Chapter 4
U.S. and International Research and Development: Funds and Alliances

Contents

Highlights

National Trends in R&D Expenditures

- **Expenditures on research and development (R&D) performed in the United States reached a record-setting high in 1997, exceeding an estimated $200 billion for the first time.** In addition, the rate of growth in R&D investment in the mid-1990s was the highest it has been since the early 1980s, in contrast to a period earlier in the decade when increases in R&D spending failed to keep pace with inflation.

- **Profit-making companies are responsible for the current upward trend in R&D investment in the United States.** The most recent data show industrial firms providing $2 out of every $3 (an estimated $133.3 billion in 1997)—and spending $3 out of every $4 (an estimated $151.4 billion)—invested in R&D in the United States. Both proportions have been edging upward almost continuously for the past quarter century. Increases in the mid-1990s in industrial R&D are the highest recorded since the early 1980s and are largely attributable to record-setting profits, intense international competition, and the introduction of new capabilities in information technology. In addition, in many firms, external research funding is growing at a rate faster than internal spending.

- **The Federal Government, which has been steadily losing ground to industry as a national source of R&D funds, provided an estimated $62.7 billion in R&D support in 1997.** Federal R&D funding has fallen almost continuously in real terms for a decade, although the descent seems to have tapered off in the mid-1990s. In 1997, federal agencies provided 30 percent of all monies spent on R&D in the United States, down from 46 percent a decade earlier (at the peak of the defense buildup).

- **The decline in federal R&D funding is reflected in data for each of the R&D-performing sectors—except academia—but is most visible in data showing federal support of industry R&D.** In other words, the impact of defense downsizing on R&D performance can be seen most clearly in the industry-reported R&D numbers. In 1997, federal support of industry-performed R&D was an estimated $20.8 billion, down about $8 billion from 10 years earlier. Between 1987 and 1997, the federal share of total industry R&D performance declined dramatically—from 32 percent to an unprecedented 14 percent. It should be noted that the federal share of the industry total has been shrinking almost continuously since at least 1970, because industry's own funding has either outpaced or has not declined as rapidly as federal support.

- **Academia is the only R&D-performing sector that did not experience a cutback in federal support during the 1990s.** The annual rate of growth in federal support, however, has been falling fairly steadily for more than a decade, e.g., little real growth is expected for 1995-97. The growth-rate decline can be attributed to efforts to balance the budget and reduce the deficit.

- **All three categories of R&D funding—basic research, applied research, and development—contributed to the overall growth in R&D spending in the United States in the mid-1990s: all three are at their highest levels ever recorded, in both current and constant dollars.** All of the growth, however, took place in the private sector. In terms of R&D financial support, the Federal Government's share of total funding for each of the three categories dropped between 1987 and 1997, with particularly severe declines for applied R&D.

- **The nonmanufacturing sector now accounts for approximately one-fourth of all industrial R&D investment in the United States; this is considerably greater than in earlier decades.** This higher profile is largely attributable to the growth of the information technology (especially software) and biotechnology industries. Firms in these two categories could seem to be taking over the annual list of the 100 largest R&D-performing companies.

- **Among the six largest R&D-performing manufacturing industries, companies classified in the electrical equipment industry exhibited both the largest absolute increase ($8.2 billion) and the highest percentage increase (92 percent) in nonfederal R&D expenditures between 1991 and 1995.** The additional electrical equipment industry monies appear in the electronic components segment, which accounted for 56 percent of R&D dollars in that industry in 1995 and experienced a three-fold increase in R&D spending between 1991 and 1995.

- **Pharmaceutical companies' R&D spending nearly tripled between 1985 and 1995.** The most prominent trend in the drugs and medicines industry has been the melding of pharmaceutical and biotechnology research: e.g., more than one-third of drug companies' R&D projects are primarily biotechnology-related. In addition, the rapid growth of R&D dollars reflects the high cost of research directed at the discovery of cures and treatments for diseases like AIDS, other viruses, and drug-resistant bacteria.

- **Total federal R&D obligations were an estimated $68.1 billion in fiscal year 1997, 12 percent below the 1989 level (in real dollars), the peak year of federal R&D investment.** Defense downsizing, which affected programs at both the Departments of Defense (DOD) and Energy, fueled the overall decline.

- **For the first time since 1981, DOD is expected to account for less than half (48 percent) of the federal R&D total.** The DOD share of federal R&D spending has been declining steadily since the mid-1980s. In 1986, at the height of the defense buildup, it accounted for approximately two-thirds of the total.

- **Cooperative R&D is now an important tool in the development and leveraging of science and technology (S&T) resources. There has been a major upswing in the number of inter- and intra-sector and international S&T partnerships since the early 1980s.** For example, the annual number of new research joint ventures has been growing in most years, with the largest increases occurring in 1995 and 1996, bringing the total number of these research collaborations up to 665 by the end of 1996.

- **The increase in research joint ventures may reflect, to some extent, companies' participation in the U.S. Department of Commerce's Advanced Technology Program (ATP).** Between 1990 and 1996, more than $2 billion in public and private funds were invested in 288 ATP projects. ATP funding was cut substantially in 1996.

- **Technology transfer activities became an important mission component of federal laboratories in the late 1980s.** Although more than 3,500 new cooperative research and development agreements (CRADAs) were executed between 1992 and 1995, government agencies now seem to be backing away from these collaborative research arrangements. The U.S. Council on Automotive Research—better known as the Clean Car Agreement or the Partnership for a New Generation of Vehicles—executed 32 CRADAs in 1995.

- **The elimination in 1995 of the Technology Reinvestment Project affected DOD's "dual-use" strategy of providing financial support to the private sector to develop and deploy those technologies with likely applications in both the commercial and military sectors.** This project was replaced in 1997 by the much smaller Dual-Use Applications Program.

International Trends in R&D Expenditures

- **The United States accounts for roughly 44 percent of the industrial world's R&D investment total and continues to outdistance, by more than 2 to 1, the total research investments made by Japan, the second largest performer.** Not only did the United States spend more money on R&D activities in 1995 than any other country, it also spent nearly as much by itself as the rest of the major industrialized "Group of Seven" (G-7) countries combined—Japan, Germany, France, the United Kingdom, Italy, and Canada. However, in terms of nondefense R&D spending, combined expenditures in these six countries exceeded nondefense R&D spending in the United States by 18 percent.

- **Total R&D expenditures stagnated or declined in each of the largest R&D-performing countries in the early 1990s, but has since recovered in the United States and Japan.** There was a worldwide slowing in R&D spending in both large and small industrialized countries in the early 1990s. In fact, inflation-adjusted R&D spending fell for three consecutive years (1992, 1993, and 1994) in both the United States and Japan. Among the G-7 countries, only the United States and Japan showed an apparent reversal of this trend in 1995, with the total R&D effort rising by 6 percent in both countries (in constant dollars and constant yen, respectively).

- **In the United States, the recovery in total R&D spending and its R&D to gross domestic product (GDP) ratio is the result of increased expenditures on nondefense activities.** The U.S. R&D/GDP ratio has inched back up to 2.6 percent in 1997 from its 16-year low of 2.4 percent in 1994. The 1997 nondefense R&D/GDP ratio is estimated at 2.2 percent, a historical high.

- **R&D spending in the Russian Federation and in many of the former communist countries in Europe remains considerably below levels in place before the introduction of market economies.** R&D downsizing and restructuring of obsolete, state-owned (generally military-oriented) enterprises are necessary to establish viable commercial and scientific R&D infrastructures in these countries.

- **Worldwide changes in the R&D landscape are presenting governments with unparalleled issues of refocusing purpose and direction in S&T policies.** Defense R&D has been substantially reduced not only in the United States, but also in the United Kingdom and France, where the national defense share of the government R&D total has declined from 44 to 41 percent, and from 40 to 29 percent, respectively.

- **Among nondefense functions, U.S. Government R&D spending for health is far greater than for any other activity.** From 1990 to 1998, health R&D is expected to grow by 26 percent (in constant dollars) while funding for all other nondefense functions will grow by just 3 percent. Health programs now account for 18 percent of the U.S. federal R&D funding total. The greatest growth is in AIDS-related research.

- **Many countries have put into place fiscal incentives to increase the overall level of R&D spending and to stimulate industrial innovation.** Practically all industrialized countries (including the United States) allow industry R&D expenditures to be 100 percent expensed in the year they are incurred, and about half of the countries (including the United States) provide some type of additional R&D tax credit. From 1990 to 1996, U.S. industry received an estimated $12 billion through tax credits on incremental research and experimentation expenditures. About 15 states offer additional R&D tax credits.

- **Industrial firms increasingly are using global research partnerships to strengthen core competencies and expand into technology fields critical for maintaining market share.** Since 1986, companies worldwide have entered into over 4,000 known multi-firm R&D alliances involving strategic high-technology activities. More than one-third of these alliances were between U.S. firms and European or Japanese firms. Most of the alliances were created to develop and share information technologies.

- **Substantial R&D investments are made by U.S. companies overseas.** From 1985 to 1995, U.S. firms' investment in overseas R&D increased three times faster than did company-funded R&D performed domestically (10.1 percent versus 3.4 percent average annual constant-dollar growth). Equivalent to about 6 percent of industry's domestic R&D funding in 1985, overseas R&D now amounts to 12 percent of U.S. industry's on-shore R&D expenditures. Most (72 percent) of U.S.-funded R&D was performed in Europe—primarily Germany, the United Kingdom, and France. Pharmaceutical companies accounted for the largest industry share (20 percent of U.S. 1995 overseas R&D), which was equivalent to 25 percent of their domestically financed R&D.

- **Substantial R&D investments are made by foreign firms in the United States.** From 1987 to 1995, inflation-adjusted R&D growth from majority-owned U.S. affiliates of foreign firms averaged 12.5 percent per year. This growth contrasts favorably with the implied 3 percent average annual rate of increase in U.S. firms' domestic R&D funding. R&D expenditures in the United States by foreign companies are now roughly equivalent to U.S. companies' R&D investment abroad. Germany, Switzerland, the United Kingdom, France, and Japan collectively account for 75 percent of this foreign funding. Foreign-funded research in 1995 was concentrated in drugs and medicines, industrial chemicals, and electrical equipment industries. More than 670 foreign-owned R&D facilities are located in the United States.

Introduction

Chapter Overview

Research and development (R&D) appear to be benefiting from the economic prosperity of the mid-1990s. Businesses are thriving, jobs are being created, and inflation seems to be under control. A recent upswing in R&D spending in the United States is paralleling these and other positive economic trends. The annual level of R&D expenditures is estimated to have reached a record-setting high in 1997, exceeding $200 billion for the first time. In addition, the rate of growth in R&D investment is the highest it has been since the early 1980s, a welcome contrast to a period in the early 1990s when it failed to keep pace with inflation.

What is driving the recent R&D expansion? It is not the Federal Government, which is continuing to curtail its support of defense-related R&D activities. Instead, almost all of the acceleration is attributable to industrial firms. Simply stated, many firms are reaping record profits, which is creating a profitable climate for investment in innovation.

The invention of new and improved products, processes, and services has a pervasive impact on the quality of life and the standard of living in the United States and other industrialized nations. Although a negligible portion of the world's financial and human resources is invested in R&D, advancements in science and technology (S&T) often deliver huge and crucial payoffs in terms of economic growth and prosperity, national security, and the health and well-being of society.

A number of new trends in U.S. R&D investment have emerged in recent years, including:

- an increase in R&D performed in the service sector;
- an upsurge in state spending on cooperative technology programs;
- elevated political disharmony over the role of the Federal Government in technology development;
- a mushrooming of collaborative R&D efforts within and across sectors and with international partners; and
- rapid growth in global R&D expenditure flows, including the rise in U.S. industry's overseas R&D investment, as well as foreign R&D investment in the United States.

In addition, federal spending priorities have been gradually changing. Pressure to balance the budget, combined with defense downsizing (which began in the late 1980s after the end of the Cold War), is continuing to reshape industrial R&D activity, redefine the mission of federal laboratories, and reduce the growth rate of university research programs.

The purpose of this chapter is to track these and other U.S. and international trends in S&T financial investment.

Chapter Organization

This chapter is divided into five parts. The first, "National Trends in R&D Expenditures," contains information on overall R&D funding trends by source of support, performing sector, and character of work (including national investment in basic research, applied research, and development).

The second part, "R&D Patterns by Sector," takes a closer look at each of the R&D-performing sectors. R&D funding and performance by individual manufacturing and nonmanufacturing industries are examined; also included are discussions of R&D investment by size of company, R&D intensity, and federal support of industry-performed R&D. Next, the most recent data on federal R&D obligations are examined, including statistics for individual agencies and those classified by character of work. The part concludes with a discussion of federal laboratories' role in national R&D performance.

The third part is devoted to domestic partnerships and alliances within and between sectors. Topics covered include industrial R&D consortia, technology transfer activities, and other federal programs designed to stimulate joint research activities.

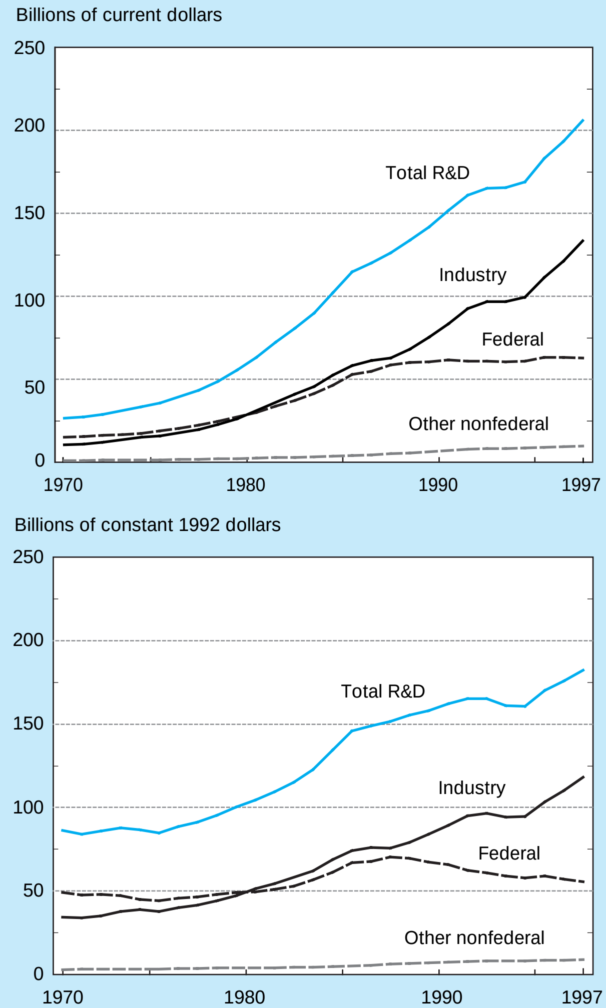
International R&D comparisons are examined in the fourth part, beginning with an analysis of absolute levels of total and nondefense spending by country, R&D/gross domestic product (GDP) ratios, patterns of sector-specific funding and performance, and information on the character of R&D work undertaken. Next, considerable detail on governments' R&D focus and priorities is provided, including a summary of recent policy initiatives and fiscal incentives for R&D performance.

The fifth part summarizes the growth of international R&D and technology alliances and the rapid rise in industrial R&D investment flows into and out of the United States.

National Trends in R&D Expenditures

R&D investment in the United States hit a record-setting high in 1997, reaching an estimated $205.7 billion. Total R&D expenditures climbed an average of 4.3 percent per year (in inflation-adjusted dollars) between 1994 and 1997, the highest rate of growth recorded since the early 1980s. In addition, R&D as a percentage of GDP has also been rising. The recent expansion in R&D investment marks a change from the late 1980s and early 1990s when there was relatively little or no real growth in overall R&D spending. (See figure 4-1 and appendix tables 4-3 and 4-4.)

Figure 4-1.
National R&D funding, by source



See appendix tables 4-5 and 4-6.

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National R&D Trends by Source of Support and Performing Sector

The two major sources of financial support for R&D are industry and the Federal Government, which together supply approximately 95 percent of all funds spent on R&D performed in the United States. The remaining 5 percent is provided primarily by universities and colleges and nonprofit organizations. (See figures 4-1 and 4-2 and appendix table 4-5.)

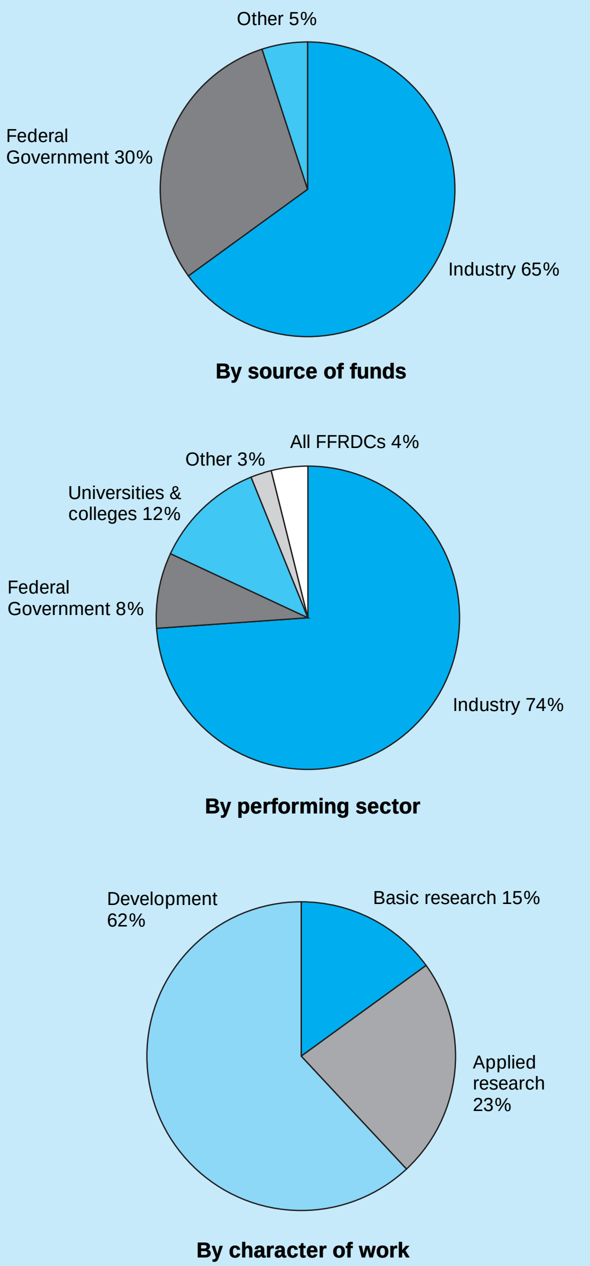
In addition to financing R&D, industry and the Federal Government are two of the three leading R&D-performing sectors. The third is academia, which is a distant second to industry in terms of R&D performance. In 1997, industry, academia, and the Federal Government were responsible for spending 74 percent, 12 percent, and 8 percent, respectively, of the total dollars invested in R&D in the United States. Two other groups—federally funded research and development centers (FFRDCs)[1] and nonprofit organizations—accounted for 4 percent and almost 3 percent, respectively.[2] (See figure 4-2 and appendix table 4-3.)

Industry's share of national R&D performance has been rising steadily—from two-thirds of the total in the 1970s to nearly three-fourths in the late 1990s. During the same period (1970-97), the academic share rose slightly—from 9-10

[1]FFRDCs are organizations exclusively or substantially financed by the Federal Government to meet particular requirements or to provide major facilities for research and associated training purposes. Each center is administered by an industrial firm, an individual university, a university consortia, or a nonprofit organization.

[2]R&D performed by state and local governments is not included in the national R&D totals. In 1995, R&D performance by these entities was estimated to be less than $400 million. (See "State R&D Issues: High Geographic Concentration and New Data on State Government R&D Support.")

Figure 4-2.
National R&D expenditures: 1997



NOTE: FFRDCs are federally funded research and development centers.
See appendix tables 4-3, 4-5, 4-7, 4-11, and 4-15.

Science & Engineering Indicators – 1998

percent to 12-13 percent—and the federal share dropped by half—from 16 percent to 8 percent.

Sources of R&D Support

For-profit companies are responsible for the current upswing in R&D investment in the United States. In addition to being both the largest source of R&D funds and the leading R&D-performing sector in the United States, industry also had the highest percentage increase in R&D investment in the mid-1990s.

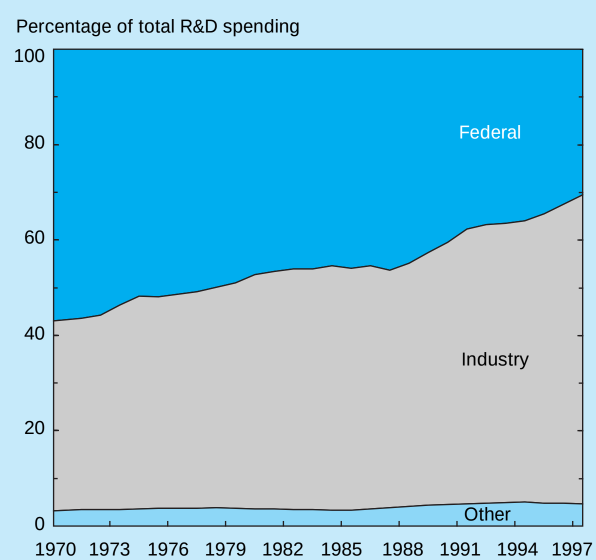
In 1997, companies provided an estimated $133.3 billion to finance R&D performed in the United States, or 65 percent of the national total. Nearly all of this amount—$130.6 billion—was spent on R&D conducted in industrial facilities; the remaining $2.7 billion was used to support R&D activities undertaken on university and college campuses and at other nonprofit organizations. (See appendix table 4-5 and text table 4-1.)

Industry-Supplied Funding on the Rise. In 1980, industry surpassed the Federal Government as the leading supplier of R&D dollars in the United States. (See figure 4-1.) During the early and mid-1980s, industry's share of the total stood at about 50 percent. Then, in 1987, the proportion of total industry-supplied R&D monies began an almost continuous decade-long climb, with the most recent data showing industrial firms providing $2 out of every $3 spent on R&D in the United States. (See figure 4-3.)

Between 1995 and 1997, industry R&D financing grew at an estimated average annual rate of 7.7 percent per year in inflation-adjusted dollars. This trend contrasts with that of the preceding three-year period 1991-94, when no real growth occurred in industry-supplied R&D dollars.

Federal R&D Funding in Decline. While industry's share of the national total was expanding, the federal share was shrinking. In 1997, the Federal Government provided an estimated $62.7 billion in R&D support, with federal agencies providing 30 percent of all monies spent on R&D in the United States, down from 46 percent a decade earlier (at the peak of the defense buildup). (See figure 4-3.) Federal R&D funding declined almost continuously in real terms between 1987 and

Figure 4-3.
National R&D expenditures, by source of funds



See appendix table 4-5. *Science & Engineering Indicators – 1998*

Text table 4-1.
U.S. R&D expenditures, by performing sector and source of funds: 1997
(Millions of U.S. dollars)

R&D performer	Total	Source of R&D funds: Industry	Federal Government	Universities and colleges[a]	Other nonprofit institutions	Percent distribution, performers
Total	205,742	133,308	62,745	6,278	3,411	100.0
Industry	151,418	130,631	20,787	–	–	73.6
Industry-administered FFRDCs[b]	2,273	–	2,273	–	–	1.1
Federal Government	16,450	–	16,450	–	–	8.0
Universities and colleges	24,031	1,710	14,285	6,278	1,759	11.7
University-administered FFRDCs	5,405	–	5,405	–	–	2.6
Other nonprofit institutions	5,520	967	2,900	–	1,653	2.7
Nonprofit-administered FFRDCs	644	–	644	–	–	0.3
Percent distribution, sources	100.0	64.8	30.5	3.1	1.7	

– = unknown, but assumed to be negligible; FFRDCs = federally funded research and development centers

NOTES: Data are estimated. Details may not add up to totals because of rounding.

[a]Includes an estimated $1.8 billion in state and local government funds provided to university and college performers.

[b]FFRDCs conduct R&D almost exclusively for use by the Federal Government. Expenditures for FFRDCs therefore are included in federal R&D support, although some nonfederal R&D support may be included.

See appendix table 4-5. *Science & Engineering Indicators - 1998*

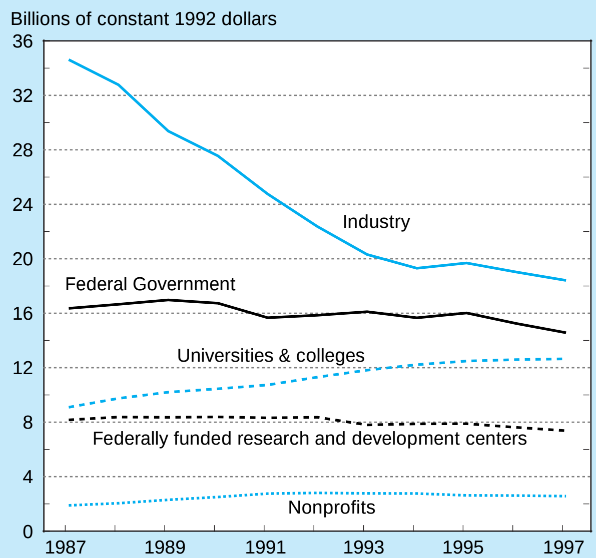
1997 at an average annual rate of 2.3 percent; the greatest drop occurred during the late 1980s and early 1990s. The descent seems to be tapering off, however, as the annual average decline was estimated to be only 1.3 percent between 1994 and 1997.

Most federal R&D dollars (74 percent) are not used in government-owned laboratories, but rather to finance R&D performed in other sectors. (See figure 4-4 and appendix table 4-5.) For example:

- ♦ Industry received an estimated $20.8 billion in federal R&D support in 1997 (one-third of all federal R&D monies), mainly to finance defense-related R&D performed under contract to the Departments of Defense (DOD) and Energy (DOE).
- ♦ Academic institutions acquired an estimated $14.3 billion in federal R&D support in 1997; almost all of the funds supported basic and applied research in the natural sciences and engineering. In addition to the acquisition of new knowledge and breakthrough discoveries, research conducted on university and college campuses provides another widely acknowledged benefit by playing a key role in training the next generation of scientists and engineers. (For more information, see chapters 2 and 5.)
- ♦ FFRDCs and other nonprofit organizations received an estimated $8.3 billion and $2.9 billion, respectively, in federal R&D funds in 1997.

Declining Federal Support Felt Most by Industry. The decline in overall federal R&D funding is reflected in data for each of the R&D-performing sectors—except academia—but is most visible in data showing federal support of R&D performed by industry. During the period 1992-97, federal R&D funds supplied to industry are expected to show an average annual decline of 3.8 percent in constant 1992 dollars. Cutbacks in federal intramural and federal support to nonprofit organizations are expected to average 1.7 percent, and to all FFRDCs, 2.5 percent in constant 1992 dollars.

Figure 4-4.
Federal R&D support, by performing sector



See appendix table 4-6. *Science & Engineering Indicators – 1998*

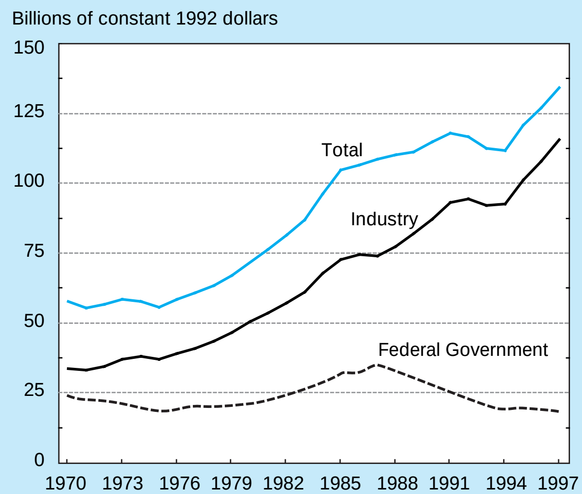
In 1987, federal R&D funds accounted for just under one-third of all monies spent by companies to conduct R&D. The most recent data show the shrinking of that proportion down to an unprecedented 14 percent. (It should be noted that the federal share of the industry total has been shrinking almost continuously since at least 1970, because industry's own funding has either outpaced or has not declined as rapidly as federal support.) Although defense downsizing seems to have taken a heavy toll on industry R&D, it is becoming increasingly difficult to track defense R&D flows from federal agencies to industry performers. (See "Accounting for Defense R&D: Discrepancies Between Performer- and Source-Reported Expenditures.")

The curtailment of federal R&D work has had a definite negative effect on overall industrial R&D performance numbers since 1987. That is, the estimated 6.1 percent average annual decline in federal R&D support in constant dollars registered between 1987 and 1997 partially offset growth in industry's own funding during the 10-year period. In 1997, federal support of industry-performed R&D was an estimated $20.8 billion, down about $8 billion from the level reported 10 years earlier. (See figure 4-5 and appendix table 4-3.)

Annual Growth Rate Slowed for Academia. It is important to emphasize that the annual level of federal R&D support to academia has not declined. However, the annual rate of growth in federal support has been falling fairly steadily (in all but two of the past dozen years). The growth rate decline can be attributed to efforts to balance the budget and reduce the deficit. Although academia is the only R&D-performing sector not to have experienced a cutback in federal support during the 1990s, little real growth is expected for 1995-97. While the annual level of total R&D support supplied by each of the five sources that fund academic R&D rose in both current and constant dollars (see appendix tables 4-3 and 4-4), all the sources exhibited 1992-97 growth rates that were about half or less than half of those recorded for the previous five-year period.

Despite the recent slowing, federal support to universities and colleges is estimated to have increased at an average annual constant-dollar rate of 2.3 percent between 1992 and 1997. Industrial support is estimated to have had the largest percentage increase during that period (32 percent), but federal agencies registered the largest absolute increase ($3 billion) in support of academic R&D.

Figure 4-5.
U.S. industrial R&D expenditures, by source of funds



See appendix table 4-4. *Science & Engineering Indicators – 1998*

National R&D Trends by Performing Sector

Industry. In the United States, industry has always been the overwhelming leader in R&D performance. In 1997, three-fourths of the total amount spent on R&D performed in the United States financed work undertaken in industrial laboratories. The total cost of that work is estimated at more than $150 billion; federal agencies supplied approximately 14 percent of those funds. (See appendix table 4-3.)

A surge in industrial R&D performance during the mid-1990s saw annual expenditure increases estimated at 6.2 percent per year in inflation-adjusted dollars between 1994 and 1997—the highest rate recorded since the early 1980s. The expansion is entirely attributable to companies' own R&D investment and represents a turnaround from the preceding three-year period when the annual level of industrial R&D outlays failed to keep pace with inflation. (See figure 4-6 and appendix tables 4-3 and 4-4.)

Academia. Academia is a distant second to industry in terms of R&D performance, with total expenditures amounting to an estimated $24 billion, or 12 percent of the national total. Until 1989, the academic sector ranked third in total R&D performance in the United States, after industry and the Federal Government. Since 1983, however, the annual rate of increase in R&D performed at universities and colleges has been higher than that of the Federal Government (except in 1995). As a result, academic institutions moved into second place in 1989, behind industry. (See figure 4-6 and appendix table 4-3.)

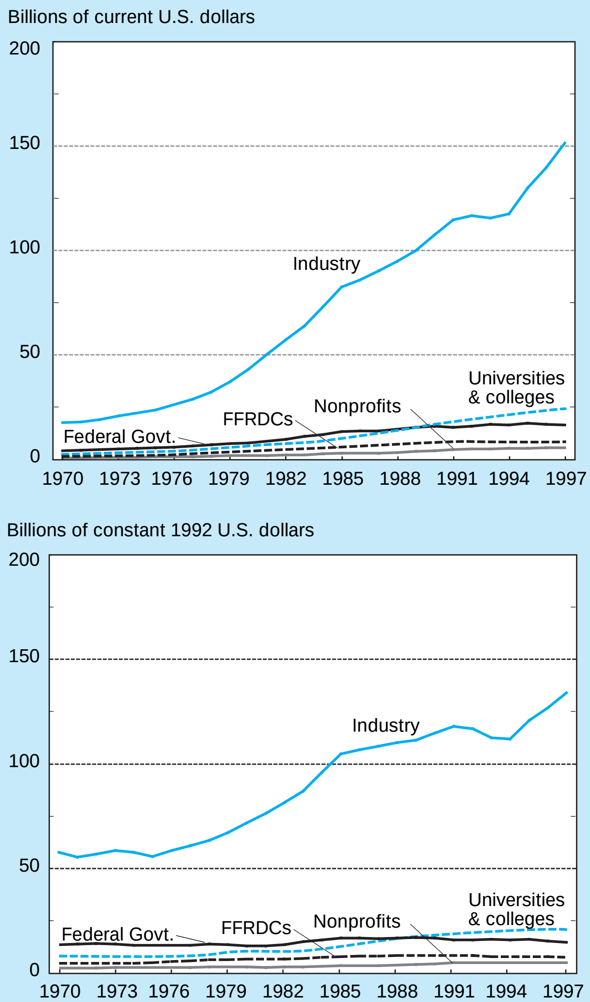
Academia has not suffered a constant-dollar decline in R&D performance in more than two decades. (See appendix table 4-4.) However, the annual real rate of growth has been decreasing almost continuously since 1986, falling from a near 10 percent increase that year to an estimated 1 percent change in both 1996 and 1997.

Most of the research performed on university and college campuses is funded by the Federal Government. In 1997, federal agencies provided an estimated $14.3 billion, or about 60 percent of the total. Academic institutions supplied an estimated $4.5 billion of their own funds,[3] state and local governments and nonprofit organizations each contributed $1.8 billion, and industry provided $1.7 billion.

Federal R&D support to academia has been increasing continuously since 1982, even after adjustment for inflation. Although industry supplies fewer R&D dollars to universi-

[3]See chapter 5, "Financial Resources for Academic R&D," for an explanation of universities' and colleges' "own funds" and for further discussion of academic R&D expenditure trends.

Figure 4-6.
National R&D funding, by performer



NOTE: FFRDCs are federally funded research and development centers. See appendix tables 4-3 and 4-4.

Science & Engineering Indicators – 1998

ties and colleges compared to the other four sources, it has an even longer track record than the Federal Government of continuous growth in the support of academic research—stretching back to at least 1970. As a result, the proportion of academic R&D expenditures supplied by industry has been rising fairly steadily, although industry still represents only a fraction (7 percent) of total academic R&D support.

Federal Agencies. Federal entities spent an estimated $16.5 billion on intramural R&D in 1997. (Most federal R&D monies are not spent in federally run facilities, but in other sectors.) Federal intramural R&D, as a percentage of total national R&D performance, has been falling fairly steadily since the early 1970s and was down to an estimated 8 percent in 1997.

In real terms, federal intramural R&D is at its lowest point since 1982 because of cutbacks in DOD laboratories; these labs accounted for 56 percent of the intramural total in 1982, but less than half (48 percent) in 1997. The most recent data show an estimated constant-dollar decline of 9 percent between 1995 and 1997. (See figure 4-6 and appendix table 4-4.)

R&D Support and Performance by Character of Work

The traditional way to analyze trends in R&D performance is to examine the amount of funds devoted to basic research, applied research, and development. (See "Definitions.") These terms are convenient because they correspond to popular models that depict innovation occurring in a straight-line progression through three stages: (1) scientific breakthroughs from

Definitions

The National Science Foundation uses the following definitions in its resource surveys. They have been in place for several decades and are also generally consistent with international definitions.

Basic research. The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind. In industry, basic research is defined as research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest.

Applied research. Applied research is aimed at gaining the knowledge or understanding to meet a specific, recognized need. In industry, applied research includes investigations oriented to discovering new scientific knowledge that has specific commercial objectives with respect to products, processes, or services.

Development. Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes.

Budget authority. Budget authority is the authority provided by federal law to incur financial obligations that will result in outlays.

Obligations. Federal obligations represent the amounts for orders placed, contracts awarded, services received, and similar transactions during a given period, regardless of when funds were appropriated or payment required.

Outlays. Federal outlays represent the amounts for checks issued and cash payments made during a given period, regardless of when funds were appropriated or obligated.

R&D plant. Federal obligations for R&D plant include the acquisition of, construction of, major repairs to, or alterations in structures, works, equipment, facilities, or land for use in R&D activities at federal or nonfederal installations.

the performance of basic research (2) lead to applied research, which (3) leads to development or application of applied research to commercial products, processes, and services.

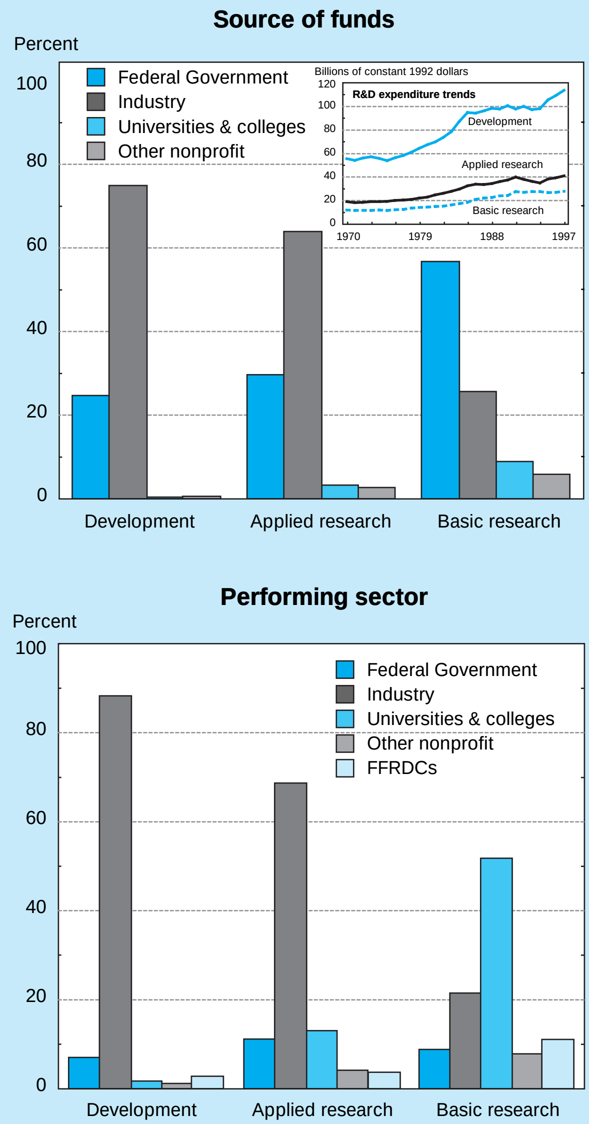
The simplicity of this approach makes it appealing to policymakers, even though the traditional categories of basic research, applied research, and development do not always ideally describe the complexity of the relationship between science, technology, and innovation in the real world.[4]

Alternative and perhaps more realistic models of the innovation process have been developed, but they are probably too complicated to be used in collecting and analyzing comparable and reliable data for policymaking purposes, and would not enable time-series analyses. Therefore, the practice of categorizing R&D expenditures into basic research, applied research, and development is unlikely to be abandoned anytime soon.

All three categories of R&D funding contributed to the overall growth in R&D spending in the United States in the mid-1990s, and all three were at their highest levels ever recorded in both current and constant dollars. (See figure 4-7.) All of the gains, however, took place in the private sector. In terms of R&D financial support, the Federal Government's share of total funding for applied research and development dropped dramatically between 1987 and 1997. For applied research, the proportion declined from 38 to 29 percent. The development loss was even more steep, falling from 46 percent of the total to 25 percent. The Federal Government's share of basic research funding also fell during the same 10-year period—from 61 percent of the total to 57 percent. (See figure 4-8.)

Most R&D dollars—an estimated $128.3 billion in 1997, or 62 percent of the total—are spent on development. Applied research accounted for an estimated 22.5 percent, and basic research for 15 percent. These proportions tend to be fairly stable over time, although percentage point changes usually occur from year to year. For example, basic research's proportion of total R&D varied from 13 to 17 percent during the last quarter century, while applied research and development ranged from 22 to 24 percent, and from 60 to 65 percent, respectively. In the mid-1990s, development increased a couple of percentage points, and basic research fell by about the same amount—probably a reflection of the expanding role of industry in national R&D performance. Industry performs relatively more development and less basic research than the other sectors.

Figure 4-7.
National R&D expenditures, by source of funds, performing sector, and character of work: 1997



NOTE: FFRDCs are federally funded research and development centers.

See appendix tables 4-3, 4-5, 4-7, 4-9, 4-10, 4-11, 4-12, 4-13, 4-14, 4-15, and 4-18.

Science & Engineering Indicators – 1998

Basic Research

In 1997, an estimated $31.2 billion was spent on basic research performed in the United States, an increase of about 4 percent in real terms over the 1995 level, and somewhat below the overall R&D increase of 7 percent during the two-year pe-

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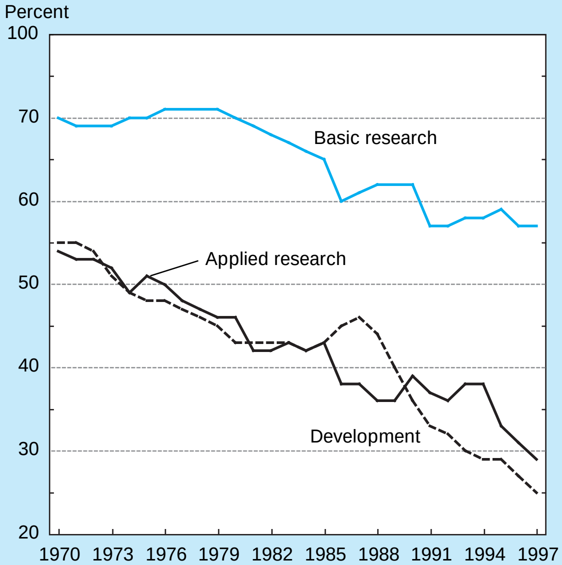
[4]See NSB (1996), chapter 4, "Alternative Models of R&D and Innovation." In a recent report, the Council on Competitiveness (1996) said "the old distinction between basic and applied research has proven politically unproductive and no longer reflects the realities of the innovation process… The United States [should adopt] a new and more up-to-date vocabulary, one that accounts for changing calculations of R&D risk and relevance over short-, medium- and long-term horizons." In its report, the Council identified three types of research (short-term/low-risk, mid-term/mid-risk, and long-term/high-risk) and the economic sectors that have primary and secondary responsibility for each.

In contrast, another recent study found that R&D managers/directors and financial officials/accountants in both manufacturing and nonmanufacturing firms generally agree that the National Science Foundation's classification of R&D expenditures into basic research, applied research, and development appropriately describes the scope of their companies' self-financed R&D activities (Link 1996a).

Figure 4-8.
The federal share of total U.S. funding of basic research, applied research, and development



See appendix tables 4-5, 4-9, 4-13, and 4-17.

Science & Engineering Indicators – 1998

riod. Most of that amount—$17.7 billion, or 57 percent of the total—was supplied by the Federal Government. Industrial firms provided $8 billion, or 25 percent of the total; universities and colleges, $2.7 billion; and nonprofit organizations, $1.7 billion.[5] (See figure 4-7 and appendix table 4-9.)

Academic Sector Performance. Although the Federal Government is the leading supplier of funds, the academic sector is the largest performer of basic research, with expenditures totaling an estimated $16 billion in 1997. Of that amount, $10 billion were federal funds. Far smaller amounts were supplied by the universities themselves, and by state and local governments, industry, and nonprofit organizations. (See appendix table 4-7.)

Financial support for basic research performed in the academic sector is not growing as fast as it did in the late 1980s and early 1990s. The average annual constant-dollar rate of growth was an estimated 2.3 percent between 1992 and 1997, down from the 4.4 percent average registered during the preceding five-year period. All five funding sources contributed to the slowdown, each exhibiting a lower rate during the period 1992-97 than during 1987-92. The drop is particularly noticeable in the largest source of funding—the Federal Government. It is estimated that between 1995 and 1997, federal funding of basic research performed in the academic sector barely kept pace with inflation. (See appendix table 4-10.)

[5]According to a recent study, only around 2 percent of basic research performed in the United States is supported by foreign sources (Cahners Research 1997).

Industry's support of research conducted on university and college campuses has always been a small but growing component of the academic research portfolio. Industry officials have tapped this resource not only to realize the beneficial results of the research they sponsor, but also to capitalize on opportunities to train future scientists and engineers, most of whom will one day be working in their laboratories.[6] Industrial support can take a number of forms, including hiring professors as consultants, funding postdoctoral joint research, and/or providing grants to individual departments (Council on Competitiveness 1996). Although only a small fraction of academic basic research is financed by industry—an estimated 6.5 percent in 1997—companies' support increased an estimated 8 percent in real terms between 1995 and 1997, the largest percentage gain of the five sources that fund academic basic research.[7]

Increasing use is being made of university research to fill gaps left when industrial basic research is curtailed, e.g., industry and university personnel have been collaborating in areas of military importance, including lasers, electronics, computing, and materials (U.S. DOD 1996). Results from an annual Industrial Research Institute survey confirm that "industry is depending more and more on academic research," e.g., the percentage of respondents anticipating increasing grants for academic R&D rose from 12 percent in 1993 to more than 20 percent in 1996 and 1998 (IRI 1997).

Industrial Performance. Industrial firms spent an estimated $6.6 billion in company and federal funds on basic research in 1997—about 4 percent of all industrial R&D expenditures. The vast majority of these funds were companies' own financial resources, which increased an estimated 14.5 percent in real terms between 1995 and 1997. (See appendix tables 4-7 and 4-8.)

The gain in industrial investment in basic research estimated for 1995-97 partially offsets a 20 percent decline that took place during the preceding four-year period when several companies' central research facilities were dismantled. That period marked the beginning of a trend toward shorter term R&D and away from fundamental research, largely "driven by the competitive environment and a motivation to extract greater value (or 'effectiveness') from R&D investments" (Larson 1997b). (See "Top 10 'Biggest' Problems for Technology Leaders.") R&D is increasingly being conducted within individual business units in a concerted effort to speed

[6]A recent study revealed that automotive industry officials are more interested in universities' preparation of students than in the usefulness of the research their companies fund. Although they praised the schools for an increased emphasis on manufacturing, they also felt "graduate programs needed to focus more on real-world concerns" (Council on Competitiveness 1996).

[7]Passage of the University and Small Business Patent Procedure Act of 1980, better known as the "Bayh-Dole Act," (see text table 4-8) spurred a major increase in research collaborations between academia and industry.

Top 10 "Biggest" Problems for Technology Leaders

The Industrial Research Institute has been surveying its membership annually since 1993 to identify the biggest problems for technology leaders. (See text table 4-2.) Results from the 1997 survey rank "managing R&D for business growth" first; this issue has increased in relative importance to the Institute's members, who ranked it fourth and fifth in 1996 and 1995, respectively. "Balancing long-term/short-term R&D objectives/focus" was identified as the second most important problem every year of the survey except 1996 (where it ranked first) and 1993 (third). "Integration of technology planning with business strategy" ranked third in three of the five years. The only item evidencing a noticeable decline in relative importance over the five-year period was "measuring and improving R&D productivity/effectiveness." Until 1996, this item was ranked first in importance; in 1996, it fell to second; and in 1997, it was ranked seventh out of the 10 problem areas.

Text table 4-2.
Top 10 "biggest" problems for technology leaders
(Percentages of total votes)

Survey item	1993	1994	1995	1996	1997
Number of total responses	248	193	258	242	223
Managing R&D for business growth	NA	NA	5.9	10.0	17.0
Balancing long-term/short-term R&D objectives/focus	10.1	12.2	11.0	12.1	14.7
Integration of technology planning with business strategy	11.0	10.2	7.4	11.2	13.0
Making innovation happen	NA	NA	7.8	9.5	10.3
Management of global R&D	3.8	2.9	3.5	4.5	5.8
Leadership of R&D within the corporation	1.7	3.2	2.3	4.2	4.0
Measuring and improving R&D productivity/effectiveness	15.2	15.1	11.5	11.8	4.0
R&D portfolio management	4.2	5.0	4.5	4.5	4.0
Selling R&D internally or externally	5.0	3.1	2.6	4.2	4.0
Information technology	NA	NA	NA	NA	3.1
Percent of responses (top 10)	40.9	39.5	56.5	72.0	79.9

NA = not asked

SOURCE: Industrial Research Institute, Member Company Representatives, "The 'Biggest' Problems Technology Leaders Face," *Research Technology Management,* September-October, 1997.

Science & Engineering Indicators - 1998

commercialization of new technology.[8] Company research is being "driven largely by business needs rather than curiosity" (Larson 1997b).

In some companies, corporate support for "central research" activity has been eliminated completely. Allied Signal, Armstrong World Industries, and W.R. Grace are recent examples (Larson 1997b). A survey of leading firms found that central corporate funding accounted for about 50 percent of central laboratories' budgets in 1988, but had fallen to about 40 percent in 1993, and that the percentage of corporate funding in the budgets of business unit laboratories decreased from almost 40 percent to less than 10 percent during the same period (Bean 1995). According to another study, increases in outlays for applied research and development have occurred at the expense of basic research (Cahners 1997).

Federal Intramural Performance. An estimated $2.7 billion was used to finance basic research performed in federally run laboratories in 1997. The annual level of funding has not changed appreciably in real terms since the early 1980s. (See appendix table 4-8.) In addition, basic research as a percentage of total federal intramural research has held constant (at 15 to 16 percent) for the past two decades, indicating that applied research and development—not basic research—have felt the brunt of the general overall decline in federal intramural research.

Applied Research

An estimated $46.2 billion was spent on applied research performed in the United States in 1997—22.5 percent of the national R&D total. The annual level of investment in applied research increased an estimated 17 percent in real terms between 1994 and 1997, more than offsetting a brief 12 per-

[8]In the late 1980s and early 1990s, U.S. industrial firms were forced to react to a significantly changed climate for R&D financing. Product development was becoming increasingly market- rather than technology-driven, and profit margins were eroding because of escalating international competition and ever-shortening product life cycles. To survive, companies had to cut costs and take a shorter term, more product-oriented approach to R&D. (See "Top 10 'Biggest' Problems for Technology Leaders.") To meet these challenges, many corporate central research laboratories were either eliminated or downsized, and business units took on a more prominent role in performing and funding R&D. In addition, outsourcing R&D to other companies and organizations became a popular way of keeping costs under control. The benefits of these changes are reflected in the enhanced competitiveness of U.S. companies in the mid-1990s. Not only has the conversion of R&D results into new products, processes, and services been accelerated, but the United States has strengthened its position in several critical technologies in which it had been slipping (Council on Competitiveness 1996).

cent downward slide that occurred during the preceding three-year period. (See figure 4-7 and appendix table 4-12.)

Industry, which led the growth in investment in applied research in the mid-1990s, is both the leading supporter and performer of this type of research. (See figure 4-7 and appendix table 4-13.) In 1997, companies were the source of an estimated $29.4 billion spent on applied research undertaken in the United States, up 36 percent in real terms over the 1994 level. In general, the proportion of all applied research funds originating in industry has been increasing steadily—up from 42 percent of the national total in 1970 to 64 percent estimated for 1997. Industry's *performance* of applied research was at an all-time high in 1997, an estimated $31.7 billion (in current dollars), or 69 percent of the national total.

The industrial increase in applied research performance is noteworthy on two counts. First, it represents a major turnaround from the early 1990s when, between 1991 and 1994, the annual number of dollars invested in applied research conducted in industrial laboratories dropped more than $1 billion per year. Second, it is entirely attributable to companies' own investment. After a series of hefty increases in federal funding of industry-performed applied research in the early 1980s, the level fell each year between 1985 and 1988, recovering in the late 1980s only to decline again in the 1990s. In 1997, federal support of industry-performed applied research was just over half the level recorded seven years earlier. (See appendix table 4-11.)

While industry financing of applied research was recovering from an early 1990s slump, federal funding continued to slide downward, falling an estimated 12 percent in real terms between 1993 and 1997. The Federal Government's share of the total has been declining since 1970, falling from 54 percent that year to an estimated 29 percent in 1997. The decline was particularly steep during the recent period 1994-97, with a drop of 9 percentage points.

Between 1994 and 1997, a major disparity marked trends occurring among the three leading R&D-performing sectors. While the annual level of spending on applied research undertaken in industrial laboratories rose a healthy 28 percent in constant 1992 dollars, the amount spent by academic institutions increased by a modest 5 percent, and the Federal Government's intramural performance was off by about 6 percent. (See appendix table 4-12.)

The annual level of federal investment in intramural applied research held steady in the mid-1990s at approximately $5 billion; therefore, only a slight reduction in real dollars took place between 1994 and 1997. In contrast, during the preceding six-year period, federal intramural applied research outlays increased an average of 3.4 percent per year in constant dollars. (See appendix tables 4-11 and 4-12.)

Development

Six out of every 10 dollars spent on R&D in the United States are spent on development. (See figure 4-7 and appendix tables 4-3 and 4-15.) An estimated $128.3 billion was used to finance the development of new and improved products, processes, and services in 1997. This amount exceeds the 1995 level by about 8 percent, after adjustment for inflation. Development funding has been increasing in real terms since 1993, offsetting sluggish growth in the late 1980s and a brief downward trend in the early 1990s which reflected defense spending cutbacks following the end of the Cold War. Federal support of development projects has been falling in real terms since 1987 at an average annual rate of 4.5 percent, although the rate of decline slowed in the most recent years. In contrast, industry financing increased 5.1 percent per year during the decade. (See appendix table 4-18.)

As with applied research, industry is both the leading provider of development funds and the major performer. Industry became the largest source of development funds in 1974, overtaking the Federal Government that year. Because the advancing and applying of new technologies are activities undertaken almost exclusively in the private, for-profit sector, almost all development dollars (nearly 90 percent) are spent by industrial firms. In 1997, industrial firms were the source of an estimated $95.9 billion, or about 75 percent, of the total spent on development in the United States. All but $313 million of these funds were spent in industrial laboratories. The federally provided share of development funds is now estimated to be 25 percent of the total, down from more than 40 percent during the late 1970s and 1980s. (See figure 4-8 and appendix table 4-17.)

Of the estimated $113 billion spent by industry on development in 1997, an estimated $17.5 billion, or 15 percent of the total, came from federal contracts. Since 1987, a major curtailment in the annual level of federal funding was reported by industry, with a 27 percent (47 percent after adjustment for inflation) drop being registered between 1987 and 1997. (See appendix tables 4-15 and 4-16.) The most recent data show the other R&D-performing sectors—including the Federal Government, universities and colleges, nonprofit organizations, and FFRDCs—responsible for spending only 12 percent of the national total.

As development R&D *performers*, federal agencies spent an estimated $8.7 billion in 1997, placing the Federal Government a distant second to industry in terms of development performance. The most recent data show the annual level at about $1 billion below the 1990 level. In real terms, federal intramural performance of development fell at an average annual rate of 3.7 percent between 1989 and 1997.

R&D Patterns by Sector

In this part, industry and Federal Government investment in R&D is examined in greater detail. See chapter 5 for additional information pertaining to R&D performance in the academic sector.

Industrial Research and Development

Industry is, by far, the largest R&D-performing sector. In 1997, for-profit companies spent an estimated $130.6 billion of their own (and other nonfederal) funds and $20.8 billion in federal funds on R&D performed in U.S. industrial labs.

(See figure 4-6 and appendix table 4-3.) In addition, an estimated $2.3 billion in federal funds were spent on R&D performed at FFRDCs administered by industrial firms.

Mid-1990s Expansion. Between 1993 and 1997, companies' own spending grew at an average annual rate of 5.8 percent in inflation-adjusted dollars. This mid-1990s expansion in industrial R&D activity is largely attributable to international competition; sustained, record-setting profitability; and the introduction of new capabilities in information technology. In addition, in many firms, external research funding is growing at a rate faster than internal spending (Larson 1997b). (See "External Sources of Technology Gaining in Popularity.") The most recent National Science Foundation (NSF) data show a 43 percent increase in company R&D funds contracted to outside organizations between 1994 and 1995 (NSF 1997a).

The recent upswing presents a sharp contrast to the preceding two-year period when R&D financing was relatively flat. In addition, the 1993-97 increase exceeds the 4.2 percent average annual gain recorded between 1985 and 1991.

Federal Government Share at All-Time Low. There was a time (30 years ago) when the Federal Government contributed more than half the total amount of funds spent by industry on R&D activities. Although those days are long gone, government funding did account for one-fourth to one-third of all industry R&D spending as recently as the late 1980s. (See figure 4-5.) The most recent data, however, show that proportion, at 14 percent, to be the lowest it has ever been—12 percentage points below what it was in 1989. Between 1987 and 1997, federal funding of industry-performed R&D fell at an average annual constant-dollar rate of 6.1 percent. However, the descent seems to be slowing: the estimated average yearly rate of decline for 1994-97 is less than it was earlier in the decade. (See appendix table 4-4.)

R&D in Manufacturing Versus Nonmanufacturing Industries

Probably the most striking change in industrial R&D performance during the past decade is the service sector's increased prominence. Until the late 1980s, little attention was paid to R&D conducted by nonmanufacturing companies, largely because service sector R&D activity was negligible compared to the R&D operations of companies classified in manufacturing industries.

External Sources of Technology Gaining in Popularity

There are a number of ways companies can access external sources of technology, including:

- outright acquisition,
- exclusive license,
- joint venture,
- minority equity,
- option for future license,
- joint development,
- R&D contract, and
- exploratory research funding (Chatterji 1996).

Although data on the number and value of these activities are largely unavailable, considerable anecdotal evidence indicates that outsourcing R&D is increasing. For example, aircraft manufacturers are outsourcing more of their R&D to their suppliers, subcontractors, and even customers;* they are also actively involved in joint ventures with their European counterparts (Council on Competitiveness 1996).

A number of factors make external sources of technology increasingly attractive. On the demand side are the following:

- Increased global competition has meant shorter product life cycles and faster development cycle time. To keep up with the accelerating pace of innovation, companies are increasingly having to look beyond their doors to gain access to new sources of technology.
- Downsized companies that handed out pink slips to many of their R&D professionals to reduce costs now find themselves without all the technical expertise they need.
- Collaboration enables participating companies to reduce their risks in exploring promising but highly speculative new technologies.
- Recent success stories have generated more interest in collaboration.

On the supply side, the following factors apply:

- The worldwide growth of scientific and engineering knowledge has created new, valuable—and available—information sources.
- The availability of venture capital has spurred the formation of startup companies in several high-tech areas, including biotechnology, electronics, and software, that are attractive sources of new technology.
- There is a growing workforce of technical professionals displaced by downsizing; their former employers and other organizations are eager to take advantage of their expertise and experience.

*Boeing outsourced a significant amount of R&D connected with the development of its 777 airliner, including relying on foreign firms (the Japan Aircraft Development Corporation and other firms from Asia, Europe, and Canada) for design and manufacturing expertise (Council on Competitiveness 1996).

Increase in Service Sector R&D. Prior to 1983, nonmanufacturing industries accounted for less than 5 percent of the industry R&D total. A decade later, the R&D landscape looked very different because of a ninefold increase in service sector R&D. The proportion of total industrial R&D performed by companies classified in service industries reached 26 percent in 1993 and then decreased a couple of percentage points in 1994 and 1995. (See chapter 6, figure 6-15.)

In 1995, nonmanufacturing firms' R&D outlays totaled $32 billion—$27.4 billion in funds provided by companies and other nonfederal sources, and $4.6 billion in federal funds. (See appendix table 4-19.) Data for 1991-95 show the R&D expenditures of companies classified in the service sector increasing at about the same pace as in manufacturing companies (which accounts for the 2-point decline mentioned in the preceding paragraph).

Four industry groupings account for 90 percent of the nonfederal R&D performed in the service sector:

- computer programming, data processing, other computer-related engineering, architectural, and surveying services accounted for $9.6 billion in nonfederal R&D expenditures in 1995;
- wholesale/retail trade, $7.5 billion;
- communications services, $4.8 billion; and
- research, development, and testing services, $2.8 billion.

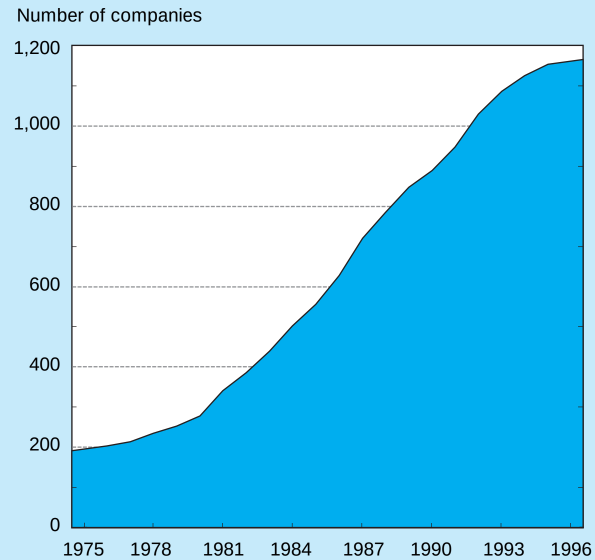
It is likely that companies formerly classified in manufacturing industries account for a sizable portion of the R&D dollars in these service sector categories (especially the top three). For example, given the growing importance of computer software (relative to hardware) and other information technologies, a classification shift from manufacturing to nonmanufacturing would not be unusual.

In addition, because the United States invests a relatively large share of its resources in health care—13.6 percent of GDP in 1995 (U.S. HHS 1996)—the increasing importance of R&D laboratories in the nation's industrial R&D portfolio is also predictable. This greater prominence can be attributed, in large part, to major advances in research on the human body, the establishment and growth of a variety of medical research facilities, and the maturing and success of the biotechnology industry. For example, between 1975 and 1996, nearly 1,000 biotechnology companies came into existence.[9] (See figure 4-9.) Many of these companies are classified in the research, development, and testing services category.

The nonmanufacturing categories also contain a significant number of small startup firms. Some of these are spinoffs from academic research—which is how many software and biotechnology companies came into being (Council on Competitiveness 1996).

[9]In addition to 1,165 "pure" biotechnology companies (the vast majority of which came into being between 1975 and 1996), the Institute for Biotechnology Information counts 234 (including 56 instrument, 48 pharmaceutical, 32 chemical, 28 agricultural, 22 diagnostic, 20 food, 13 waste and environmental, and 15 in other categories) companies that also conduct biotechnology research.

Figure 4-9.
Number of U.S. biotechnology companies



SOURCE: Institute for Biotechnology Information, U.S. Companies Database (Research Triangle Park, NC: 1997).

Science & Engineering Indicators – 1998

Manufacturing Sector. As service sector R&D became more visible, manufacturing R&D lost some of its prominence. Nevertheless, the manufacturing sector continues to dominate industrial R&D. (See text table 4-3.)

In 1995, the six largest manufacturing industries—in terms of companies' own (and other nonfederal) R&D expenditures in the United States were:

Text table 4-3.
Share of total company and other nonfederal funds, by selected R&D-performing industries
(Percentages)

	1987	1991	1995
All manufacturing industries	91.6	74.7	74.8
Chemicals and allied products	15.4	15.9	16.0
Petroleum refining and extraction	3.1	2.7	1.6
Machinery	17.2	15.1	8.9
Electrical equipment	17.0	9.8	15.7
Transportation equipment	21.9	16.4	17.8
Instruments	8.1	7.6	7.8
All nonmanufacturing industries	8.4	25.3	25.2
Communication services	1.8	4.6	4.4
Wholesale/retail trade	NA	NA	6.9
Computer programming and other related services	3.6	3.6	8.8
Research, development, and testing services	0.1	NA	2.6

NA = not available

See appendix table 4-21.

- transportation equipment, $19.3 billion;
- chemicals and allied products (which includes the drugs and medicines industry), $17.3 billion;
- electrical equipment, $17.1 billion;
- machinery (which includes companies classified as computer hardware manufacturers), $9.7 billion;
- professional and scientific instruments, $8.5 billion; and
- petroleum refining and extraction, $1.8 billion.

These six industries accounted for 91 percent of all nonfederal R&D funds spent by companies classified in manufacturing industries in 1995, the same percentage they have held since at least 1985. What has changed is their share of all industrial R&D dollars. That proportion fell from over four-fifths of the total in 1987 to two-thirds in 1991, where it has remained. (See appendix table 4-21 and text table 4-3.)

Among the six industries, companies classified in the electrical equipment industry exhibited both the largest absolute increase ($8.2 billion) and the highest percentage increase (92 percent) in nonfederal R&D expenditures between 1991 and 1995. Text table 4-3 shows a flip-flopping in proportionate share of the total for the electrical equipment and machinery industries between 1991 and 1995, with the latter losing 29 percent of its nonfederal R&D monies. (All of the cutback was in the computer segment of the industry.)

It is probably safe to assume that some part of the machinery industry's decline is attributable to a reclassification of companies into other manufacturing (e.g., electrical equipment) and nonmanufacturing (software) industries, although this scenario cannot be confirmed.[10] Likewise, the electrical equipment industry's increase may reflect some movement of companies into that industry rather than real gains in R&D investment. However, further study of NSF survey data indicates that a sizable portion of the growth is real (NSF 1998c).

All of the additional electrical equipment industry monies appear in the electronic components segment, which accounted for 56 percent of that industry's 1995 R&D dollars and whose R&D spending increased threefold between 1991 and 1995.[11] Until 1993, the communications equipment segment was the largest component of the electrical equipment industry in terms of R&D. But in 1995, that segment's R&D expenditures were less than half those of electronic components companies; undoubtedly, some of the communications equipment decline reflects a reclassification of those firms into the nonmanufacturing communication services category. (See appendix table 4-21.)

[10]The R&D cutback by computer hardware firms also reflects the industrywide trend of pulling back on central laboratory research to concentrate R&D resources on the development of new products for the marketplace (Council on Competitiveness 1996).

[11]According to the Council on Competitiveness (1996), "semiconductors, opto-electronics, and flat panel displays (FPD) are the three critical building blocks of electronics systems expected to drive U.S. competitiveness in electronics markets over the next several decades." Although the United States regained the lead in the global semiconductor market in 1992, Japan is still out-distancing the United States in FPD technology, opto-electronics, and photo-lithography.

In the largest R&D-performing industry—transportation equipment—a 7.9 percent average annual increase (in inflation-adjusted dollars) in R&D outlays by companies classified in the motor vehicles subgroup was somewhat offset by a 2.7 percent average annual decline in the aircraft and missiles segment between 1991 and 1995.[12] The 1991-95 increase in automakers' R&D financing represents a major acceleration in R&D investment by that industry, compared to the preceding six-year period. (See appendix table 4-21.)

It is no secret that U.S. companies' share of the world market for motor vehicles declined during the last quarter century; however, the industry has rebounded in recent years. The success and strength of foreign competitors actually led to a "revolution" of sorts in U.S. laboratories and production facilities. R&D has played a major role in the changes, in terms of both the automobile production process and the product itself.[13] The overriding goal of the changes has been to reduce production costs and time-to-market. Success is evident: where it once took five or more years for a new car to go from drawing board to showroom, it now takes only two to three years (Council on Competitiveness 1996).

Two of the largest R&D-performing industries—petroleum refining and extraction, and chemicals (excluding drugs and medicines)—did not contribute to the overall growth in nonfederal industrial R&D expenditures between 1991 and 1995.[14] Companies in these two industry classifications reported cutbacks of 29 percent and 5 percent, respectively, in their R&D financing during the period. (See appendix table 4-21.) R&D downsizing is reflected in oil and chemical companies' drop in ranking in *Inside R&D*'s annual list of the top 100 R&D performers in the United States. (See appendix table 4-23.) It is possible that at least some of the decline in in-house R&D reported by companies in these two industries is being offset by their increasing participation in industrial R&D consortia. (See "Industrial R&D Consortia.") Chemicals and petroleum companies are some of the most active members of research joint ventures (RJVs), especially those devoted to environmental R&D (Link 1996b).

[12]U.S. firms are no longer the sole players in the world's commercial aircraft market. In addition to the entry of Airbus Industrie Groupe (a consortium sponsored by the German, French, British, and Spanish governments), other nations (including Japan, China, Russia, and Taiwan) have announced their intentions to enter the commercial aircraft market (Council on Competitiveness 1996).

[13]For example, all U.S. firms have adopted Japanese manufacturing practices such as concurrent engineering. In addition, various computer and information technologies have improved and accelerated the design, development, and production of motor vehicles. Computer-based technologies have also played a major role on the product side, i.e., electronic systems have revolutionized the way vehicles are operated. In large part, these new capabilities reflect manufacturers' compliance with government regulations. Meeting standards for mileage, emissions, and safety has played a major role in shaping manufacturers' research agendas (Council on Competitiveness1996).

[14]According to chemicals industry officials, long-term R&D—i.e., the development of new processes and products—has been sacrificed in favor of seeking incremental improvements for existing products. Until the 1980s, one-third to one-half of R&D expenditures in the industry went to new processes and products; that proportion is now down to less than one-fourth (Council on Competitiveness 1996).

In contrast to the lackluster R&D performance of industrial chemicals companies, the other part of the chemicals industry, which consists of pharmaceutical companies, had its usual healthy increase in R&D spending: the size of drug companies' R&D programs nearly tripled between 1985 and 1995.[15] (See appendix table 4-21.)

The most prominent recent trend in the drugs and medicines industry has been the melding of pharmaceutical and biotechnology research; more than one-third of drug companies' R&D projects are primarily biotechnology-related. In addition, pharmaceutical companies have been collaborating with and acquiring biotechnology companies to take advantage of the latter's potentially lucrative discoveries. The success and strength of the biotechnology industry is reinforcing the United States's world leadership position in drug research (Council on Competitiveness 1996).

R&D Expenditures by Size of Company

In 1995, 122 companies with more than 25,000 employees spent more than $1 million each on R&D in the United States (NSF 1998c). Prior to 1990, this group of companies accounted for more than half the nonfederal R&D expenditure total. That share has fallen below 50 percent because the R&D outlays of small and medium-size firms have been increasing faster than those of large companies. For example, small firms (those with fewer than 500 employees) accounted for 14 percent of all nonfederal R&D expenditures in the United States in 1995, up from 10 percent five years earlier. (See appendix table 4-21.)

Industrial R&D Concentrated in Large Firms. Despite small companies' rising share, U.S. industrial R&D expenditures remain heavily concentrated in a relatively small number of relatively large firms. For example, approximately 25 U.S. companies spent more than $1 billion each on R&D in 1996; 10 years earlier, only 10 companies exceeded the billion-dollar mark (Technical Insights 1997 and 1988). In 1995, the 4 largest R&D-performing companies (in terms of nonfederal funds) accounted for 16 percent of the total amount spent; the 20 largest, 34 percent; and the 200 largest, 68 percent. The last statistic, however, is less than the 80 percent and 82 percent shares held in 1990 and 1985, respectively. (See appendix table 4-24.)

Changes in Rankings of Top 100 R&D Companies. During the 10-year period 1986-96, major membership changes occurred in *Inside R&D*'s annual list of 100 leading R&D-performing companies. (See appendix table 4-23.) The three largest R&D-performing companies, however, were the same in both years, although the second- and third-ranked companies switched places. That constant may be one of few revealed by comparing the lists from 1986 and 1996, as major changes in rankings occurred among the remaining 97 entries:

- The 5th, 8th, 9th, and 10th largest R&D-performing companies in 1996 were not among the top 10 in 1986.[16] Of these four companies, Intel made the largest leap, going from 46th to 9th place.
- Computer software and some computer hardware, pharmaceutical, and biotechnology firms are increasingly prominent R&D performers. Companies like Microsoft, Sun Microsystems, Inc., Amgen, Seagate Technology, Genentech, Compaq Computer, and Cisco Systems were not even on the list in 1986 and now rank in the top 50. Microsoft spends more on R&D than all but a dozen U.S. companies.
- Almost half the companies ranked 50 to 100 are new to the list. Nearly every company in the new group is either a software (e.g., Novell) or a biotechnology (e.g., Genzyme) company.
- Almost all petroleum and chemical companies fell sharply in rank. For example, Dupont dropped from 6th to 26th place, and Dow Chemical and Monsanto dropped from 15th and 17th, respectively, to 31st and 32nd. The largest oil company, Exxon, was 41st in 1996, compared to 14th 10 years earlier.
- Aerospace firms also declined in ranking. Boeing and McDonnell Douglas (which merged in 1997) dropped from 11th to 20th and from 19th to 55th, respectively. The combination of Lockheed and Martin Marietta and all the other acquisitions that now comprise a single company (see figure 4-10) kept Lockheed Martin at number 30.

R&D Intensity

In addition to absolute levels of and changes in R&D expenditures, another key indicator of the health of industrial science and technology is R&D intensity. R&D is similar to sales, marketing, and general management expenses in that it is a discretionary—i.e., non-direct-revenue-producing—item that can be trimmed when profits are falling. There seems to be considerable evidence, however, that R&D enjoys a high degree of immunity from belt-tightening endeavors—even when the economy is faltering—because of its crucial role in laying the foundation for future growth and prosperity.

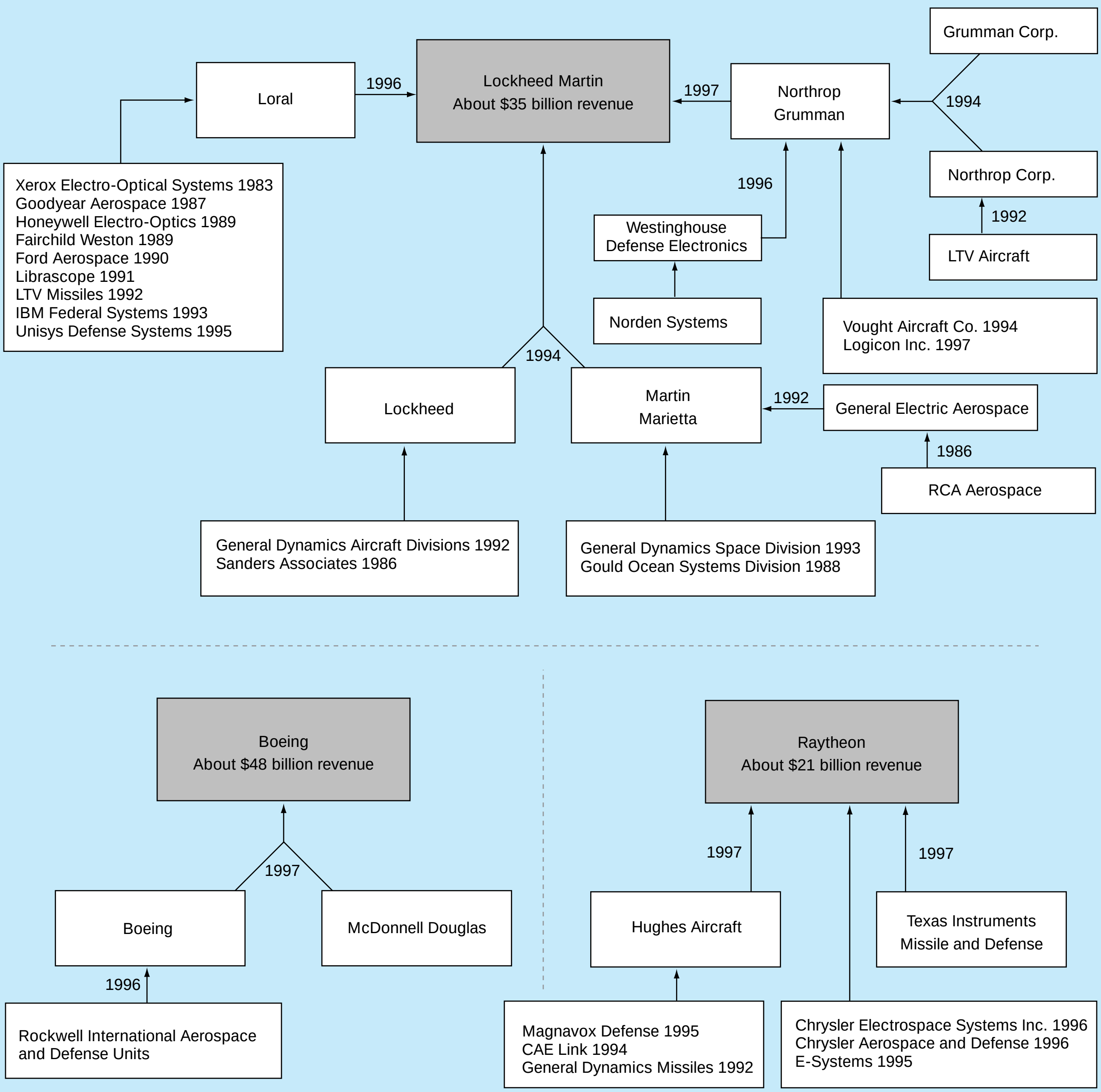
There are a number of ways to measure R&D intensity, but the one used most frequently is the ratio of R&D funds to net sales. This statistic provides a way to gauge the relative importance of R&D across industries and firms in the same industry.

The ratio of R&D dollars to net sales tends to be fairly stable over time, although year-to-year changes of 0.1 to 0.2 percentage points are not uncommon. Also, there are

[15]The rapid growth of R&D dollars in the drug industry reflects the high cost of research directed at discovering cures and treatments for diseases like AIDS, other viruses, and drug-resistant bacteria. In addition, managed competition is changing the way drug companies do business in the health care services marketplace; new constraints on pricing could adversely affect R&D (Council on Competitiveness 1996).

[16]Lucent Technologies (ranked sixth in 1996) was split off from ATT in 1996. As a result, Lucent got ATT's top-10 berth on the list, and ATT (ranked 4th in 1986) ranked 36th in 1996. Another company, TRW, restated its R&D expenses reported to the Securities and Exchange Commission in 1996 to include *all* "sponsor-supported" R&D, which means that federal R&D funds are now included in the company's total. As a result, the company earned the seventh highest spot on the 1996 top-100 list.

Figure 4-10.
Consolidation of the U.S. aerospace industry into the "big three"



NOTE: In March 1998, the U.S. Department of Justice sued to block Lockheed Martin's purchase of Northrop Grumman.

SOURCE: J. Mintz, "How a Dinner Led to a Feeding Frenzy," *Washington Post,* July 4, 1997; and company sources.

Science & Engineering Indicators – 1998

substantial differences between industries. (See appendix table 4-25 and text table 4-4.)

In 1994 and 1995, the most recent years for which data are available, nonfederal R&D spending as a percentage of net sales for all R&D-performing companies classified in manufacturing industries was 2.9 percent. This ratio was four-tenths of a percent less than that recorded for the peak year 1992 and was the first dip below 3.0 percent in 10 years. (See figure 4-11 and appendix table 4-25.) Despite the decline, it is still safe to assume that little change has occurred in the level of importance accorded R&D relative to other discretionary expenditures. That is, roughly the same proportion of compa-

Text table 4-4.
Industry segments with the highest and lowest company (and other nonfederal) R&D funds/net sales ratios: 1995
(Percentages)

Industry segment	R&D funds/net sales ratio
Highest ratios	
Drugs and medicines	10.4
Office, computing, and accounting machines	8.1
Communication equipment	8.0
Electronic components	8.0
Optical, surgical, photographic, and other instruments	8.0
Scientific and mechanical measuring instruments	6.6
Aircraft and missiles	4.2
Lowest ratios	
Textiles and apparel	0.9
Lumber, wood products, and furniture	0.7
Petroleum refining and extraction	0.7
Food and tobacco products	0.5
Primary metals	0.5

See appendix table 4-25.

Science & Engineering Indicators - 1998

nies' income was devoted to R&D throughout the late 1980s and early 1990s.[17] Minor fluctuations indicate that R&D is able to hold its own during recessionary periods such as that experienced in the early 1990s and in periods of recovery when profits are outpacing R&D investment.

Disparity in R&D Intensity Across Sectors. As previously mentioned, R&D intensity differs significantly across industries. (See text table 4-4.) Individual industry ratios range from a high of 10.4 percent in the pharmaceutical industry to a low of 0.5 percent in the food and primary metals categories.[18] The pharmaceutical industry has led all other industries since 1993, a reflection of the risky and complex nature of drug research; in 1995, it had the only double-digit ratio. Among the least R&D-intensive industries, only the petroleum industry ranked among the six largest R&D-performing industries.

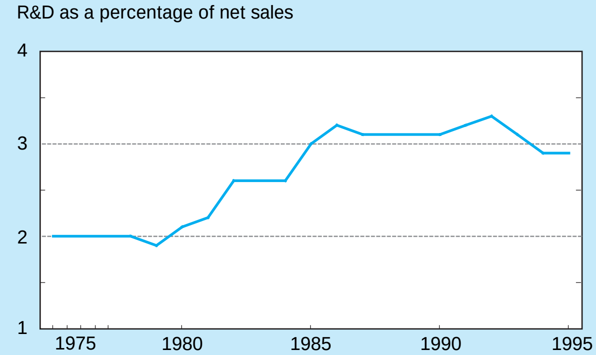
Federal R&D Funds

In 1997, industrial firms spent an estimated $20.8 billion in federal funds on R&D activities. As mentioned earlier in this chapter, federal R&D support to industry has been declining almost continuously since 1987.

[17]It is important to note that there were significant increases in the overall R&D funds/net sales ratio between 1981 and 1982 (from 2.2 percent to 2.6 percent) and between 1984 and 1986 (from 2.7 percent to 3.2 percent). Prior to 1982, company R&D funds as a percentage of net sales had been in the 2.0 percent range for 20 years.

[18]R&D outlays in the semiconductor equipment and materials industry are estimated to be about 12 to 15 percent of sales (Council on Competitiveness 1996). The broad industry classification system used in NSF's industrial R&D survey tends to mask pockets of high-tech activity.

Figure 4-11.
Total nonfederal R&D funding as a percentage of net sales for all manufacturing industries



See appendix table 4-25. *Science & Engineering Indicators – 1998*

The aircraft and missiles industry is the leading recipient of federal R&D funds. Interestingly, this industry formerly accounted for more than two-thirds of all federal monies spent by companies; however, the most recent company-reported data (1995) show it accounting for less than one-half of federal funds. (See appendix table 4-22 and "U.S. Aerospace Firms' Declining Government Sales Offset by Growing Civilian Market.")

A spate of mergers and restructurings has taken place in recent years among defense contractors. Like the "big three" automakers, there are now the "big three" aerospace companies. (See figure 4-10.) For more information on industry's defense-related R&D, see "Independent Research and Development Provides Additional Defense Funding."

Patterns of Federal R&D Support

R&D consumes only a fraction—less than 5 percent—of all public expenditures in the United States. (See "R&D Faring Relatively Well Despite Fiscal Austerity.") Despite their lack of prominence within a trillion-dollar budget, R&D funding trends reflect overall national priorities, including the emphasis on deficit reduction and the shifting balance between defense and domestic programs. For example, a reduction in defense-related programs, facilitated by the end of the Cold War, has been partially offset by increases in support for civilian R&D programs—especially those aimed at improving disease diagnosis and treatment, technological competitiveness, and the environment.

Total federal R&D obligations were an estimated $68.1 billion in fiscal year (FY) 1997, 12 percent below the peak 1989 level (in inflation-adjusted dollars).[19] Defense downsizing, which affected programs at both DOD and DOE, fueled the overall decline. (See appendix table 4-27.)

[19]An alternative method for measuring federal R&D investment, called the Federal Science and Technology budget, was proposed in 1995 by the National Academy of Sciences. (See "The Federal Science and Technology Budget.")

U.S. Aerospace Firms' Declining Government Sales Offset by Growing Civilian Market

Data from the Aerospace Industries Association (AIA) show sales of aerospace products and services falling from $116 billion in 1991 to $90 billion in 1995, then increasing to $120 billion in 1998 (AIA 1997). The recent increase is attributable to growing sales to commercial customers, although DOD remains the industry's largest single customer. But while DOD used to account for two-thirds of aerospace sales (between 1984 and 1987), it now accounts for slightly more than a third. AIA data show DOD purchases from the aerospace industry declining from $61.8 billion in 1987 to an estimated $42.6 billion in 1998.* In 1998, for the first time, all federal agencies together accounted for less than half of all aerospace sales; from 1984 through 1987, they accounted for approximately three-fourths.

Product group data also show the shift from military to civilian customers:

*DOD data are a combination of two accounts: (1) procurement and (2) research, development, test, and evaluation.

- Sales of military aircraft fell from $43.7 billion in 1987 to an estimated $30.4 billion in 1998. They now account for 25 percent of all aerospace-related sales, down from nearly half in 1987.
- AIA data show civilian airliner sales surpassing those of military aircraft for the first time in 1997. In 1998, civilian planes and jets are estimated to be 41 percent of all aerospace-related sales, up from only 17 percent in 1987.
- Annual sales of missiles fell 43 percent in the 1990s—from a peak of $14.2 billion in 1990 to $8.0 billion estimated for 1998. As a percentage of all aerospace-related sales, missiles fell from 13 percent in 1990 to 7 percent in 1998.
- Space sales (now just over a quarter of all aerospace-related sales) increased steadily between 1982 and 1992, fell slightly between 1992 and 1994, then increased again to $32.8 billion estimated for 1998.

Independent Research and Development Provides Additional Defense Spending

In addition to the federal R&D obligations discussed in this chapter, DOD's Independent Research and Development (IR&D) Program enables industry to obtain federal funding for R&D conducted in anticipation of government defense and space needs. Because it is initiated by private contractors themselves, IR&D is distinct from R&D performed under contract to government agencies for specific purposes. IR&D allows contractors to recover a portion of their in-house R&D costs through overhead payments on federal contracts on the same basis as general and administrative expenses.

Until 1992, all reimbursable IR&D projects were to have "potential military relevance." Because of the concern that defense cutbacks would reduce civilian R&D—not only in the level of commercial spillovers from weapons research but, more importantly, in reduced DOD procurement from which IR&D is funded—the rules for reimbursement were eased and the eligibility criteria broadened.* Reimbursement is now permissible for a variety of IR&D projects of interest to DOD, including those intended to enhance industrial competitiveness, develop or promote dual-use technologies, or provide technologies for addressing environmental concerns.

In 1996, industrial firms were estimated to have incurred minimally $3.0 billion in IR&D cost, of which $2.9 billion was deemed eligible for reimbursement. The government reimbursed $1.9 billion, or 66 percent of the IR&D total. As a result of the expanded reimbursement eligibility criteria, the amounts reimbursed have held rather steady at about $2 billion per year since 1984. (See appendix table 4-56.) As an equivalent proportion of combined DOD and National Aeronautics and Space Administration (NASA) industrial R&D support, IR&D fell from 11 percent in 1984 to 7 percent in 1996, although this figure is undoubtedly on the low side as a result of accounting and statistical changes. Previously, contractors with auditable costs of $40 million or more were included in the IR&D statistics. The current threshold now includes only those firms with auditable costs of more than $70 million. NASA also reimburses IR&D costs and closely follows DOD procedures. The statistics provided here include reimbursements from NASA. It remains unclear whether changes in the rules governing IR&D have had their intended effect on industrial activity.

*See NSB (1991) for a brief description of how reimbursement for IR&D was until recently determined. The National Defense Authorization Act for Fiscal Years 1992 and 1993 (P.L. 102-190) provided for the gradual removal of limitations on the amount DOD will reimburse contractors for IR&D expenditures and partially eliminates the need for advance agreements and technical review of IR&D programs.

The Federal Science and Technology Budget

In a 1995 report (NAS 1995) members of a National Academy of Sciences committee proposed an alternative method of measuring the Federal Government's S&T investment. According to committee members and other policymakers, this new approach—titled the Federal Science and Technology (FS&T) budget—provides a better way to track and evaluate trends in public investment in R&D.

The FS&T budget is actually a subset of what is usually referred to as the federal budget for research and development. Advocates of the new approach contend that the traditional method of counting federal dollars spent on R&D overstates the actual amount of federal R&D investment, because certain items are included that should not be. Although no one discounts the importance of production engineering, testing and evaluation, and upgrade of aircraft and large weapons systems, FS&T budget proponents contend that these activities should not be counted as R&D because they do not involve the discovery of new knowledge or the creation of new technologies. Moreover, they are not "major contributor[s] to economic growth, national security, health, [and] quality of life."

If the FS&T were used instead of the traditional budget to evaluate federal R&D investment, DOD's R&D numbers would look quite different. The $25 billion in FY 1997 DOD obligations slated for "major systems development" would no longer be considered R&D and therefore would be subtracted from DOD's total R&D obligations of $33 billion. Doing so would leave $8.0 billion in the FS&T budget, or $3.9 billion in DOD-sponsored research and $4.1 billion in advanced technology development.* In addition, FS&T budget data would show a 9.1 percent decline in DOD R&D obligations between FYs 1994 and 1997—about twice the percentage decline registered when performing a conventional analysis of DOD's R&D investment. (See text table 4-5.)

For all other federal agencies except DOD, the National Academy of Sciences estimates a 3.5 percent increase in the FS&T budget between FYs 1994 and 1996, compared to a 7.4 percent increase using the traditional method.

*DOD's S&T base provides a substantial portion of all federal support for research and generic technology development in several key areas, including computer science, electrical engineering, and materials.

Text table 4-5.
The FS&T budget for the Department of Defense:
(Millions of current U.S. dollars)

DOD R&D activity	1994	1995	1996	1997	% change 1994-97
Total, FS&T budget	8.8	8.9	8.7	8.0	–9.1
Research	4.3	4.3	3.9	3.9	–9.3
Advanced technology development	4.5	4.6	4.8	4.1	–8.9
Major systems development	25.8	25.4	25.5	25.0	–3.1
Total, traditional federal R&D budget	34.6	34.4	34.3	33.0	–4.6

FS&T = Federal Science and Technology

SOURCES: National Science Foundation, Science Resources Studies Division (NSF/SRS), *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1956-1996*, NSF 96-320 (Arlington, VA: 1996); and NSF/SRS, *Federal Funds for Research and Development: Fiscal Years 1995, 1996, and 1997*, Detailed Statistical Tables, NSF 97-327 (Arlington, VA: 1997).

Science & Engineering Indicators - 1998

Reduced DOD Prominence in Federal R&D Portfolio

For the first time since 1981, DOD is expected to account for less than half of total federal R&D obligations. (See figure 4-13.) The DOD share of federal R&D spending has been declining steadily since the mid-1980s.

DOD obligations have fallen in both current and constant dollars every year since 1992. In 1997, they stood at an estimated $33 billion, down nearly 20 percent in real terms from the 1992 level. (See appendix table 4-27.)

Despite the receding prominence of DOD in the R&D portfolio, the agency still overshadows all other federal sources of R&D dollars. The Department of Health and Human Services (HHS) is a distant second, with R&D obligations estimated at $12.2 billion in FY 1997. In contrast to the DOD trend, HHS support has been increasing steadily since 1992, although no real growth is expected between 1996 and 1997. (See figure 4-14.)

Between 1992 and 1997, HHS's R&D obligations rose an estimated average of 3.7 percent per year in real terms, and increased to 18 percent—up from 14 percent—of all federal R&D obligations during the same period. This growth reflects the steady stream of new dollars into almost all of the National Institutes of Health (NIH), which account for 95 percent of HHS R&D obligations.

R&D Faring Relatively Well Despite Fiscal Austerity

The President's FY 1998 budget calls for approximately $1.7 trillion in total government spending. Only 4.3 percent of that amount—about $72.6 billion—is designated for R&D programs (including R&D plant).

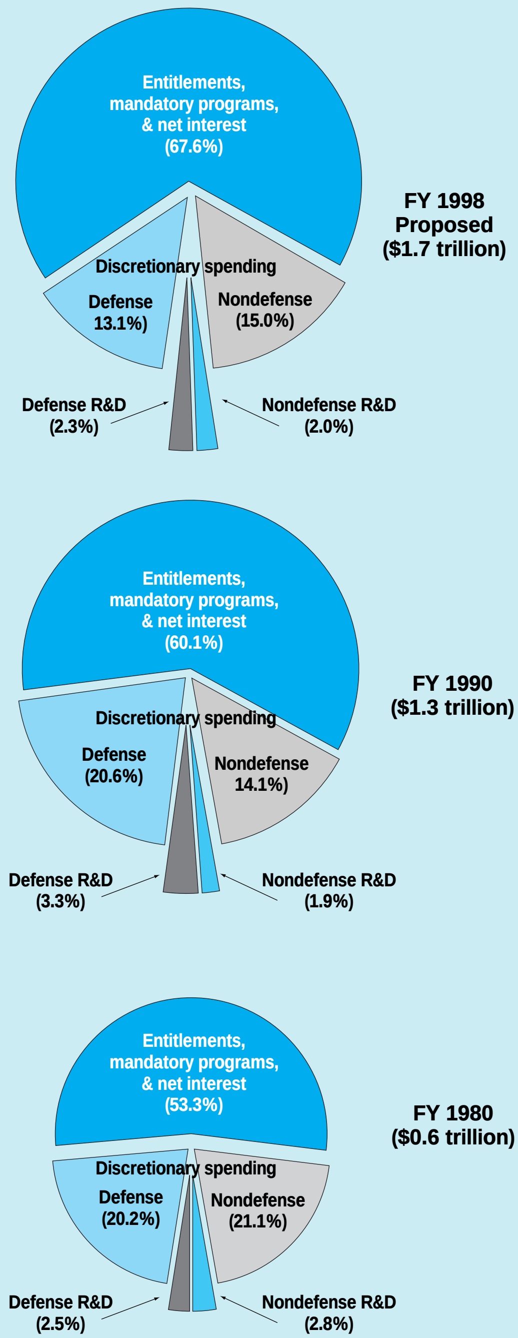
Reducing the deficit has been an overriding goal of both Congress and the Administration. To gain a better understanding of the difficulty involved in accomplishing this objective, it is helpful to split total federal spending into two categories—"mandatory" and "discretionary." Certain program expenditures, including those for Social Security, veterans' benefits, Medicare, Medicaid, and interest on the national debt, are considered mandatory items in the federal budget. That is, the government is already committed by law to financing those programs at certain levels and cannot cut them without serious political repercussions. In contrast, discretionary items, including R&D programs, do not enjoy the same level of protection from budget-cutting proposals; and the Federal Government does not *have* to, or is not already committed by law to, finance such programs at particular levels.

In recent years, the proportion of the federal budget that supports mandatory programs has been expanding while the discretionary share has been shrinking. Mandatory programs are expected to account for more than two-thirds of the total federal budget in 1998—up from less than half prior to 1980. With discretionary programs now comprising less than a third of the total budget, items like R&D and other discretionary programs are becoming increasingly likely candidates for reduction or curtailment to meet deficit-reduction targets.

Despite its increasing vulnerability, R&D has actually fared relatively well during the fiscal austerity of the 1990s. (See figure 4-12.) For example, an examination of R&D as a percentage of the total federal budget reveals the following:

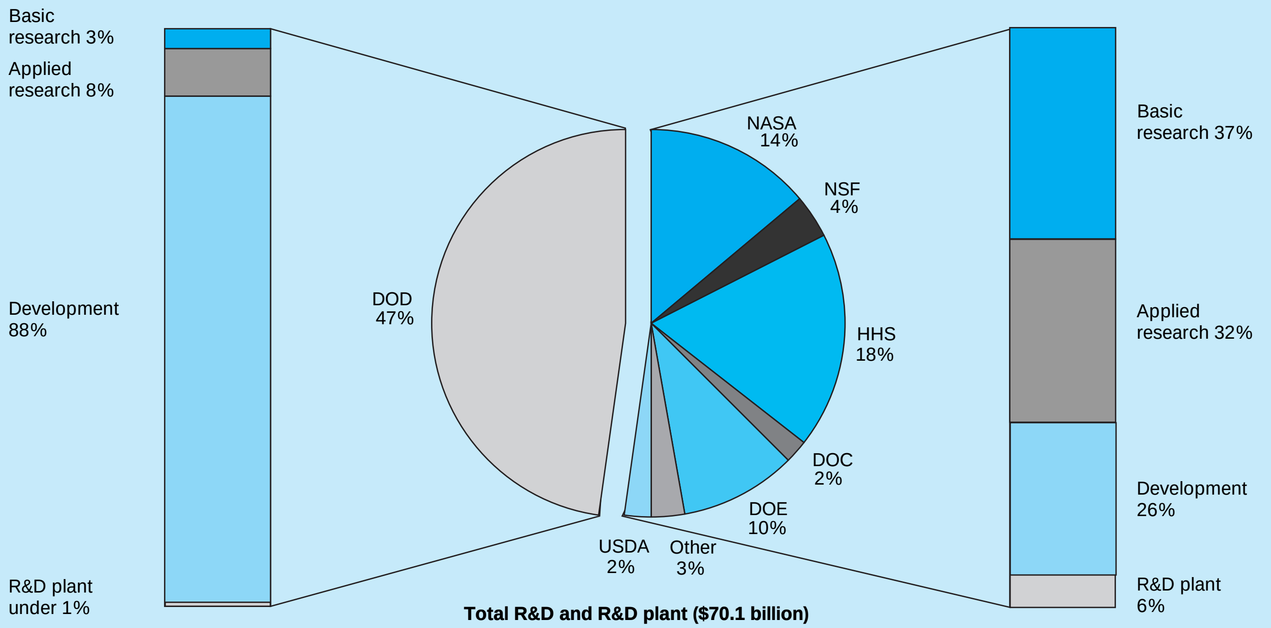
- ♦ Although all federally funded R&D is expected to fall from 5.2 percent of the budget in 1990 to 4.3 percent in 1998, nondefense R&D as a percentage of the total budget is expected to remain fairly constant at 2.0 percent during the same period.
- ♦ As a proportion of total discretionary spending, R&D has risen from 11.5 percent in 1980 to 13.0 percent in 1990 to 13.3 percent in 1998.
- ♦ Nondefense R&D as a percentage of nondefense discretionary spending has been holding fairly steady since 1980 at just under 13 percent.

Figure 4-12.
R&D share of the federal budget



See appendix table 4-26. *Science & Engineering Indicators – 1998*

Figure 4-13.
Projected federal R&D obligations, by agency and character of work: 1997



NOTE: DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = Department of Agriculture.

See appendix table 4-27.

Science & Engineering Indicators – 1998

The Major Federal R&D Agencies

In addition to DOD and HHS, five other agencies have R&D budgets that exceed $1 billion. In descending order, they are: the National Aeronautics & Space Administration (NASA), with $9.2 billion in FY 1997 obligations; DOE, $5.9 billion; NSF, $2.3 billion; the Department of Agriculture (USDA), $1.4 billion; and the Department of Commerce (DOC), $1.1 billion. These five agencies—plus DOD and HHS—account for 95 percent of U.S. Government R&D support. (See appendix table 4-27 and figure 4-13.)

NASA and NSF have seen slow expansion of their R&D budgets in the mid-1990s, with average annual constant-dollar increases estimated at 1.3 percent and 1.6 percent, respectively, between 1992 and 1997. (The NASA five-year change, however, includes a 7 percent real reduction estimated for 1996-97.)

In contrast, both DOE and USDA experienced cutbacks. DOE R&D obligations fell about 3.3 percent per year in real terms between 1992 and 1997, and USDA's dropped about 1.8 percent during the same period.

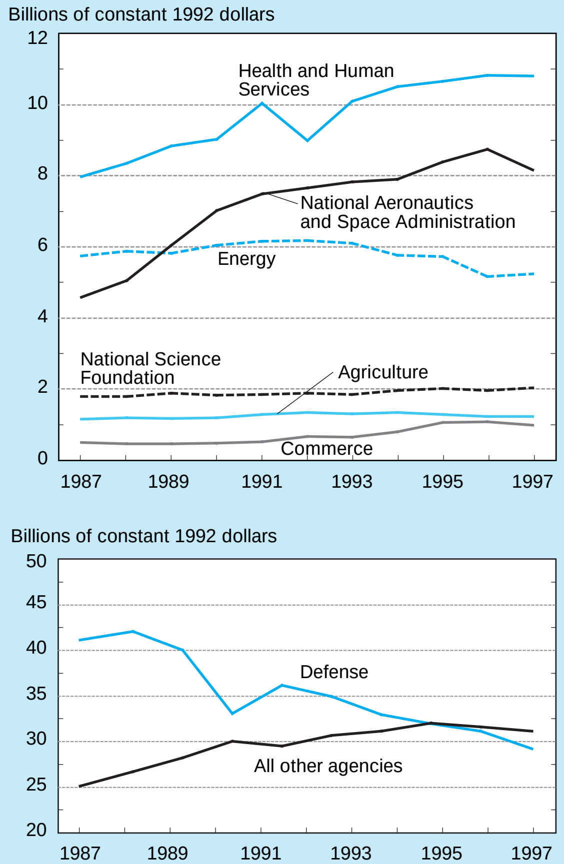
DOC joined the ranks of major R&D funding agencies a few years ago because of its Advanced Technology Program (ATP). DOC's R&D obligations topped $600 million in FY 1992, $800 million in FY 1994, and $1 billion in FY 1995, where they have remained. All of the 1990s gains are largely attributable to ATP. Although ATP continues to represent a major piece of DOC's R&D activities, its future remains uncertain.[20] (See discussion of ATP under "Federal Partnerships With Industry.") DOC's annual level of R&D obligations is expected to have dropped 9 percent in real terms between 1996 and 1997.

Mid-Size R&D Funding Agencies

Three other agencies—the Department of Transportation (DOT), the Environmental Protection Agency (EPA), and the Department of the Interior (DOI)—each have annual R&D obligations of $500 million to $1 billion. Of these mid-size R&D funding agencies, DOT is expected to have shown the largest increase in R&D obligations between FYs 1992 and 1997 (7 percent per year in real terms), while a modest gain and a decrease are expected for EPA and DOI, respectively. The increase in DOT's R&D obligations reflects that agency's current emphasis on R&D related to advancements in the areas of fuel efficiency and emissions, including the Partnership for a New Generation of Vehicles, or Clean Car Agreement. (See "Technology Transfer Activities.")

[20]Federal R&D financing has traditionally received strong bipartisan support, but a few fissures in that unanimity—differences in emphasis and priorities—surfaced in the mid-1990s. For example, the major political parties are not in agreement on the role of government in supporting programs like ATP that provide grants to profit-making companies for technology development. Budget debate over ATP has become an annual occurrence.

Figure 4-14.
National R&D obligations, by selected agency



See appendix table 4-27. *Science & Engineering Indicators – 1998*

Federal R&D Support by Character of Work

Federal obligations for basic research, applied research, and development were an estimated $14.7 billion, $14.4 billion, and $38.9 billion, respectively, in FY 1997. Overall, only modest real growth has taken place in both basic and applied research support during the mid-1990s. Each category registered average annual constant-dollar gains of 1 percent between 1992 and 1997. In contrast, the trend in federal support of development—by far the largest slice of the R&D pie—looks quite different, with development obligations in FY 1997 estimated to be more than $2 billion below the FY 1992 level. (See appendix table 4-27.)

Basic Research. After 10 consecutive years (1981-91) of annual real increases in support for basic research, the pace of federal spending on this research type slowed in the 1990s. Although total funding of basic research is continuing to grow in this decade, there have been at least two years in which annual obligations failed to keep pace with inflation.

Five agencies obligate more than $1 billion annually for basic research. HHS, with an estimated $6.6 billion in FY 1997 obligations, accounts for approximately 45 percent of the total. This is more than three times the level obligated by NSF, the second largest supporter of basic research, with $2.1 billion in estimated obligations for FY 1997. The other three agencies are DOE ($2.0 billion), NASA ($1.9 billion), and DOD ($1.1 billion). (See "DOD's Basic Research Programs.") Together, these five agencies accounted for an estimated 93 percent of all federal basic research obligations in FY 1997.

During the 1992-97 interval, HHS, with $1.5 billion, enjoyed the largest absolute increase in basic research funding, more than four times that of NSF, which had the second highest absolute increase ($348 million).

Of the five leading sources of basic research dollars, only DOD's obligations failed to keep pace with inflation between 1987 and 1997. The other four agencies registered average annual growth rates ranging from 1.1 percent for NSF to 3.4 percent for DOE during the same period. For DOE and NASA, the growth took place in the first part of the 10-year period:

DOD's Basic Research Programs

DOD's basic research effort has three main elements, listed below. The DOD organizations responsible for these three elements and their funding levels and projections are given in appendix table 4-28.

- Defense research sciences programs of the armed services, Defense Advanced Research Projects Agency, and the Office of the Secretary are the largest components of DOD's basic research portfolio, accounting for approximately 70 percent of the agency's total basic research funding. They also represent the largest source of DOD research funding for universities—most of which is conducted by single-investigator researchers—and support research undertaken by industry, government laboratories, nonprofit organizations, state and local governments, and FFRDCs.

- In-house Laboratory Independent Research is a program that finances basic research in support of laboratory missions and provides a research environment conducive to the recruitment and retention of outstanding scientists and engineers.

- The University Research Initiative is a collection of academic multidisciplinary research programs.

In 1995, DOD began funding six strategic, multidisciplinary research objectives. They are identified in DOD's Basic Research Plan as biomimetics (with $10.0 million in FY 1997 funding), nanoscience ($23.9 million), smart structures ($8.7 million), broad band communications ($17.2 million), intelligent systems ($18.5 million), and compact power sources ($9.5 million). Funding levels for each of these initiatives remained fairly constant (in current dollars) between FYs 1995 and 1997.

sizable increases between 1987 and 1992 were counterbalanced by little or no growth between 1992 and 1997.

Applied Research. The annual levels in constant 1992 dollars of total federal applied research obligations in the late 1980s and early to mid-1990s produce a wavy trend. (See appendix table 4-27.) Increases in some years were matched by cutbacks in subsequent years. Overall, the annual changes average out to a real increase of 1.7 percent per year between 1987 and 1997, similar to that for basic research. The applied research numbers illustrate that cutbacks in defense-related R&D activities are being counterbalanced by increased government investment in civilian R&D programs, e.g., health and space.

Federal funds for applied research are somewhat less concentrated than basic research dollars. Four agencies (NSF drops out of the group) obligate more than $1 billion annually for applied research and account for approximately three-fourths of all applied research obligations.

HHS is the leading supporter of applied research, with an estimated $4.2 billion in obligations in FY 1997. A large portion of these monies supports research related to the treatment of various diseases, including cancer and AIDS. DOD is second with $2.7 billion; followed by NASA, $2.4 billion; and DOE, $1.5 billion. Among these four agencies, NASA had the largest percentage increase—40 percent in inflation-adjusted dollars—in applied research obligations between 1992 and 1997. HHS registered the second highest percentage increase, with 29 percent, and the largest absolute increase at $1.3 billion.

Although both DOD and DOE recorded healthy increases in applied research obligations in the late 1980s and early 1990s, a turnaround occurred in the mid-1990s. In FY 1997, DOD obligations are estimated to be 30 percent lower in real terms than in FY 1993; DOE's obligations are expected to be down 20 percent between 1995 and 1997. (See appendix table 4-27.)

Development. There has been no real growth in federal obligations for development since FY 1992. (See appendix table 4-27.) Cutbacks averaged an estimated 3.5 percent per year between FYs 1992 and 1997.

DOD is the source of approximately three-fourths of all federal monies spent on development. In FY 1997, DOD obligations for development were an estimated $29.1 billion. These funds have been falling in both current and constant dollars almost continuously, with only two exceptions since FY 1989, the year they peaked at nearly $34 billion.

The other agencies that obligate more than $1 billion annually for development are NASA ($5.0 billion in FY 1997), DOE ($2.3 billion), and HHS ($1.4 billion). NASA development obligations more than tripled between FYs 1987 and 1996; the growth rate averaged 11.4 percent per year in real terms during the nine-year period. However, a 9 percent constant-dollar decrease is estimated for FY 1997. There has been no real growth in DOE obligations since 1990; the average annual rate of decline in constant dollars was 6.5 percent through FY 1997. In real terms, little change has occurred in the annual level of HHS development obligations since 1994, although this agency experienced a major expansion in development funding during the late 1980s and early 1990s.

R&D Agency-Performer Patterns

Most federal R&D funds are actually spent in other sectors of the economy. R&D funding relationships between supporting agencies and performing sectors are well-established and tend to be fairly stable over time. (See appendix tables 4-29 and 4-30 and text table 4-6.) Examples of these funding relationships follow:

- ♦ DOD is the source of nearly three-fourths of federal R&D monies spent by industry. Nearly 95 percent of these funds support development work. Two other agencies—NASA and DOE—provide most of the other federal R&D dollars industry receives. (Interestingly, while DOD's proportion of all federal R&D obligations slated for industry fell 3 percentage points in the mid-1990s, NASA's increased by the same amount.)
- ♦ HHS is the largest supporter of federally financed R&D performed at universities and colleges, accounting for more than half of all federal R&D funds received by these institutions. In fact, most HHS R&D obligations support work performed in academia; just under one-fifth is spent internally, mostly in NIH laboratories. HHS is also the largest supplier of federal R&D funding for nonprofit organizations. Approximately 5 percent of HHS obligations are slated for industrial firms.
- ♦ NSF and DOD are the other leading supporters of R&D conducted in academic facilities. Approximately 80 percent of the NSF research budget supports projects at universities and colleges. The bulk of the remainder is split between other nonprofit organizations (7 percent), university-administered FFRDCs (6 percent), and industry (5 percent).
- ♦ DOE and DOD supply the majority of federal R&D obligations for FFRDCs. More than half the DOE R&D budget is spent at FFRDCs.
- ♦ Unlike all other federal agencies, USDA, DOC, and DOI spend most of their R&D obligations internally. Most of the R&D supported by these agencies is mission-oriented and is conducted in laboratories run by the Agricultural Research Service, the National Institute for Standards and Technology (NIST), and the U.S. Geological Survey. (See "Other NIST Programs" and appendix table 4-31.)

About half of all federal basic research dollars are spent at universities and colleges. This sector receives most of its basic research support from HHS (53 percent in FY 1997) and NSF (23 percent). Federal obligations for basic research conducted by private firms are concentrated in the research budgets of NASA (48 percent), HHS (21 percent), and DOD (12 percent). Federal in-house work on basic research programs is distributed among several agencies, with the largest portions conducted by HHS (43 percent), NASA (18 percent), and USDA (15 percent). (See appendix table 4-29.)

Text table 4-6.
Estimated federal R&D obligations, by agency and performing sector: 1997

Character of work and performer	Performer, total obligations ($ millions)	Primary funding source		Secondary funding source	
		Agency	Percent	Agency	Percent
Total R&D	68,064	DOD	48	HHS	18
Federal intramural laboratories	16,404	DOD	48	HHS	14
Industrial firms	30,713	DOD	74	NASA	16
Industry-administered FFRDCs	1,340	DOE	70	HHS	17
Universities and colleges	12,362	HHS	57	NSF	15
University administered FFRDCs	3,231	DOE	63	NASA	25
Other nonprofit organizations	2,884	HHS	60	DOD	12
Nonprofit-administered FFRDCs	644	DOD	56	DOE	36
Total, basic research	14,372	HHS	45	NSF	14
Federal intramural laboratories	2,668	HHS	43	NASA	18
Industrial firms	1,279	NASA	48	HHS	21
Industry-administered FFRDCs	368	DOE	65	HHS	34
Universities and colleges	7,405	HHS	53	NSF	23
University administered FFRDCs	1,520	DOE	72	NASA	17
Other nonprofit organizations	1,270	HHS	77	NSF	12
Nonprofit-administered FFRDCs	83	DOE	84	HHS	13
Total, applied research	14,441	HHS	29	DOD	19
Federal intramural laboratories	5,028	DOD	21	HHS	21
Industrial firms	3,521	NASA	42	DOD	34
Industry-administered FFRDCs	637	DOE	83	HHS	12
Universities and colleges	3.418	HHS	64	DOD	9
University administered FFRDCs	611	DOE	72	NASA	15
Other nonprofit organizations	930	HHS	62	AID	12
Nonprofit-administered FFRDCs	109	DOE	63	DOD	13
Total, development	38,890	DOD	75	NASA	13
Federal intramural laboratories	8,708	DOD	75	NASA	14
Industrial firms	25,913	DOD	82	NASA	11
Industry-administered FFRDCs	334	DOE	49	DOD	44
Universities and colleges	1,539	HHS	62	DOD	21
University administered FFRDCs	1,099	DOE	46	NASA	42
Other nonprofit organizations	684	DOD	40	HHS	27
Nonprofit-administered FFRDCs	453	DOD	77	DOE	21

AID = Agency for International Development; DOD = Department of Defense; DOE = Department of Energy; FFRDCs = federally funded research and development centers; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation

See appendix table 4-29.

Science & Engineering Indicators – 1998

Federally Funded R&D Laboratories

Federal R&D obligations for all government laboratories are expected to equal $21.6 billion in FY 1997, 32 percent of total federal R&D obligations. (See text table 4-7.)

In 1995, the U.S. General Accounting Office (GAO) conducted a census of all federal laboratories that perform R&D and are operated by federal agencies or their contractors (U.S. GAO 1996a).[21] A total of 515 laboratories were counted.[22] (See appendix table 4-32.) In addition, 65 of these laboratories had a total of 221 satellite facilities, bringing the actual federal laboratory count to 736. For purposes of this discussion, GAO's identification of 515 laboratories will be used. Seventeen federal departments and independent agencies have laboratories; five (the Department of Housing and Urban Development, Department of Labor, Agency for International Development, Social Security Administration, and U.S. International Trade Commission) have none. At the time of the study, each state had a least one federal laboratory; California had the most with 46. Five laboratories (three run by USDA and two by the Navy) are located in foreign countries.

Of the 515 laboratories, 361 had operating budgets under $10 million in FY 1995, 101 were in the $10 to $100 million range, and 53 had operating budgets exceeding $100 million.

With 185, USDA had the largest number of laboratories in 1995. However, its operations are relatively small in size—with a median operating budget of $2.1 million in FY 1995. According to the GAO survey, DOD, DOE, HHS, and NASA laboratories accounted for 88 percent of all federal R&D laboratory funding in FY 1995. Although most federal laborato-

[21]Excluded from GAO's survey were facilities whose purpose is to test or analyze samples for chemical, physical, or biological properties, as these activities are not considered R&D.

[22]The various NIH institutes located at the main NIH campus in Bethesda, Maryland, were counted as a single laboratory.

Other NIST Programs

In addition to ATP, the NIST portfolio includes laboratory research and services, the Manufacturing Extension Partnership (MEP), and the Baldrige National Quality Program. These programs were funded at $265 million, $95 million, and $3 million, respectively, in FY 1997.

Laboratory Research and Services. Seven NIST laboratories and the Technology Services organization provide technical leadership for measurement and standards. The laboratories are Electronics and Electrical Engineering, Manufacturing Engineering, Chemical Science and Technology, Physics, Materials Science and Engineering, Building and Fire Research, and Information Technology. To provide NIST with the research environment required for 21st century science, a new Advanced Chemical Sciences Laboratory is under construction, and an Advanced Measurement Laboratory is planned.

Manufacturing Extension Partnership. MEP is a nationwide system of manufacturing extension centers.These centers provide all small and medium-size manufacturers in the United States access to industrial extension services. They also act as gateways into a network of technical resources, services, and expertise related to modern best business practices and manufacturing methodologies. Congress directed NIST to begin helping smaller manufacturers compete in domestic and international markets through passage of the Omnibus Trade and Competitiveness Act of 1988, which also established ATP. In contrast to the solely mission-related R&D agendas of other S&T-related programs, both MEP and ATP were designed exclusively to boost U.S. competitiveness. Since 1989, MEP has made awards for extension center operations covering all 50 states and Puerto Rico.

Baldrige National Quality Program. The Malcolm Baldrige National Quality Improvement Act of 1987 established an annual National Quality Award to promote awareness of quality excellence, to recognize quality achievements of U.S. companies, and to publicize successful quality strategies. The Secretary of Commerce and NIST were given responsibility to develop and administer the award with cooperation and financial support from the private sector. Awards may be given each year in each of three categories: manufacturing companies or subunits, service companies or subunits, and small businesses. There were 32 award winners between 1988 and 1997.

Text table 4-7.
Estimated federal R&D obligations, by selected agency and government laboratory: FY 1997
(Millions of dollars)

Agency	Total R&D	Total lab	Intramural	FFRDCs
Total, all agencies	68,064	21,618	16,404	5,214
Department of Agriculture	1,369	922	922	*
Agricultural Research Service	697	663	663	*
Forest Service	180	154	154	*
Department of Commerce	1,096	712	712	*
National Institute for Standards & Technology	542	226	226	*
National Oceanic & Atmospheric Administration	541	475	475	*
Department of Defense	32,964	8,710	7,919	791
Department of Energy	5,895	3,708	507	3,201
Department of Health & Human Services	12,185	2,632	2,362	270
National Institutes of Health	11,471	2,126	1,857	269
Department of the Interior	574	508	508	*
Geological Survey	524	483	483	*
National Aeronautics & Space Administration	9,204	3,109	2,301	808

* = less than $500,000; FFRDCs = federally funded research and development centers

NOTE: These figures reflect funding levels as reported by federal agencies in March through October 1996.

See appendix tables 4-27, 4-31, and 4-33.

Science & Engineering Indicators - 1998

ries are operated by federal agencies and employ federal personnel, 62 of the 515 were administered by businesses, universities, or other nonprofit organizations through a contract or cooperative agreement with a federal agency.

Federally Funded Research and Development Centers. Thirty-eight of the 736 federal R&D facilities identified by GAO are FFRDCs.[23] They include research laboratories, R&D laboratories, study and analysis centers, and systems engineering/systems integration centers.

[23]FFRDCs include government-owned and contractor-operated laboratories, and laboratories owned by nongovernment organizations that do virtually all their work for the government.

R&D obligations for these 38 facilities are expected to total $5.2 billion in FY 1997, about 22 percent below the 1992 level. (See appendix table 4-33.) The decline is a reflection of the overall downward trend in defense-related R&D associated with the end of the Cold War. For example, the United States no longer manufactures nuclear warheads, the former mainstay of some of the laboratories. The 1992-97 reduction also reflects removal of FFRDC designation from three facilities administered by industrial firms (formerly there were nine industry-administered FFRDCs; now there are six). Additionally, university- and nonprofit-administered FFRDCs experienced funding cutbacks of 16 percent and 14 percent, respectively, between 1992 and 1997.

Of the FY 1997 FFRDC total of $5.2 billion, $3.2 billion is obligated for 18 university-administered laboratories, $1.3 billion for the 6 run by industrial firms, and $644 million for the 14 facilities operated by nonprofit organizations.

The most well-known FFRDCs are often referred to as "national laboratories." These 10 facilities are funded by DOE. Three were established during World War II specifically to design and build nuclear weapons; six others were created in the decades immediately following the war to develop commercial applications of nuclear technology.[24]

Three of the 10 national laboratories have R&D expenditures that exceed $0.5 billion. They include Sandia, with FY 1995 obligations of about $650 million; Los Alamos, $540 million; and Lawrence Livermore, $500 million. The latter two are administered by the University of California; Sandia is administered by a subsidiary of Lockheed Martin. All three facilities recorded major cutbacks in their R&D programs in the mid-1990s. (See appendix table 4-35.)

Despite an increase in collaborative endeavors with the outside world (see "Technology Transfer Activities"), most of the work conducted at FFRDCs is still defense-related R&D funded by DOE. This agency provided an estimated $3.2 billion in FY 1997, which was a little more than 60 percent of all federal R&D dollars spent at FFRDCs. (See appendix table 4-33.) Between FYs 1992 and 1997, DOE funding fell about 20 percent. DOE is the sponsoring agency for 17 FFRDCs, 11 of which are administered by universities, 4 by industrial firms, and 2 by nonprofit organizations.

NASA now ranks second in terms of R&D funds spent at FFRDCs (it captured second place from DOD in 1995); its FY 1997 R&D obligations are expected to total $800 million. This amount is down about 23 percent from the FY 1995 level of just over $1 billion, but about the same as the levels reported in 1992 and 1994. Most of these funds are spent at the agency's only FFRDC, the Jet Propulsion Laboratory administered by the California Institute of Technology. This laboratory, which serves as NASA's principal center for solar system exploration, is now the largest single FFRDC in terms of R&D financial resources.

FFRDC R&D obligations by DOD are expected to be about $720 million in FY 1997. Total DOD support to FFRDCs has been falling every year since 1992, and now stands at less than half of the 1992 level. As mentioned, one of the reasons for the decline is the removal of FFRDC designation from three industry-administered centers; however, funding also fell about 70 percent ($465 million) at university-administered FFRDCs and 32 percent ($171 million) at nonprofit organizations between 1992 and 1997. DOD is the sponsor of 11 FFRDCs: 2 administered by universities and 9 by nonprofit organizations.

The other agencies that sponsor FFRDCs are NSF, HHS, the Nuclear Regulatory Commission, DOT, and the Treasury Department. Among this group, only NSF sponsors more than one FFRDC; four of its five centers are administered by universities, the fifth by a nonprofit organization. HHS is the fourth largest agency in terms of FFRDC support, with most of its FY 1995 obligations supporting research performed at the National Cancer Institute's Frederick Cancer Research and Development Center, which is administered by four different companies.

Inter-Sector and Intra-Sector Partnerships and Alliances

Collaboration Among Firms and Across Sectors

Cooperative R&D is now an important tool in the development and leveraging of S&T resources. For at least a decade, a combination of several factors has greatly changed the research environment, prompting the creation of inter- and intra-sector—and international—partnerships and other collaborative alliances and enabling them to flourish. Economic, legal, and cultural reasons are responsible for the growth in cooperative R&D:

- **Economic.** Collaboration allows individual partners to leverage their resources, thus reducing costs and risks and enabling research ventures that might not have been undertaken otherwise. In addition, the rise of international competition has forever changed the playing field on which U.S. companies operate, calling for new approaches to innovation.
- **Legal.** New laws have been enacted to encourage collaboration among companies and across sectors. (See text table 4-8.)
- **Cultural.** The traditional reluctance to work with researchers in other organizations—both public and private—has gradually been receding. Attitudes like "not invented here" and an anti-industry bias are far less prevalent than they used to be. Another example of this cultural change is that DOD is now looking first to the commercial sector as a source of new technology for its military needs.

[24]The 10 laboratories are Lawrence Berkeley, Los Alamos, and Oak Ridge, which were established during World War II to design and build nuclear weapons; Argonne, Brookhaven, Sandia, Idaho Engineering, Lawrence Livermore, and Pacific Northwest, which were created between 1946 and 1965 to advance civilian uses of nuclear technology; and the National Renewable Energy Laboratory, which was established to conduct R&D on alternative energy sources and was given FFRDC status in 1991(U.S. GAO 1994).

Text table 4-8.
Principal federal legislation related to cooperative technology programs

Stevenson-Wydler Technology Innovation Act (1980). Required federal laboratories to facilitate the transfer of federally owned and originated technology to state and local governments and to the private sector. The Act includes a requirement that each federal laboratory spend a specified percentage of its R&D budget on transfer activities and that an Office of Research and Technology Application be established to facilitate such transfer.

Bayh-Dole University and Small Business Patent Act (1980). Permitted government grantees and contractors to retain title to federally funded inventions and encouraged universities to license inventions to industry. The Act is designed to foster interactions between academia and the business community. This law provided, in part, for title to inventions made by contractors receiving federal R&D funds to be vested in the contractor if they are small businesses, universities, or not-for-profit institutions.

Small Business Innovation Development Act (1982). Established the Small Business Innovation Research (SBIR) Program within the major federal R&D agencies to increase government funding of research with commercialization potential in the small high-technology company sector. Each federal agency with an R&D budget of $100 million or more is required to set aside a certain percentage of that amount to finance the SBIR effort.

National Cooperative Research Act (1984). Encouraged U.S. firms to collaborate on generic, precompetitive research by establishing a rule of reason for evaluating the antitrust implications of research joint ventures. The Act was amended in 1993 by the National Cooperative Research and Production Act, which let companies collaborate on production as well as research activities.

Federal Technology Transfer Act (1986). Amended the Stevenson-Wydler Technology Innovation Act to authorize cooperative research and development agreements (CRADAs) between federal laboratories and other entities, including state agencies.

Omnibus Trade and Competitiveness Act (1988). Established the Competitiveness Policy Council to develop recommendations for national strategies and specific policies to enhance industrial competitiveness. The Act created several new programs, including the Advanced Technology Program and the Manufacturing Technology Centers in the Department of Commerce's National Institute of Standards and Technology to help U.S. companies become more competitive.

National Competitiveness Technology Transfer Act (1989). Part of the Department of Defense authorization bill, this act amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.

Defense Conversion, Reinvestment, and Transition Assistance Act (1992). Initiated the Technology Reinvestment Project to establish cooperative, interagency efforts that address the technology development, deployment, and education and training needs within both the commercial and defense communities.

SOURCE: C. Coburn, ed., *Partnerships: A Compendium of State and Federal Cooperative Technology Programs* (Columbus, OH: Battelle Press, 1995).

Although data on financial resources invested in multi-firm and multi-sector collaborative R&D activities are sparse, evidence reveals a major upswing in the number of S&T partnerships since the early 1980s.[25] (See "State R&D Issues: High Geographic Concentration and New Data on State Government R&D Support.") Several indicators of cooperative R&D activity are discussed in this section, which covers only domestic alliances. See "International Strategic Technology Alliances," later in this chapter, for information on international collaborative R&D activities.

Industrial R&D Consortia

In the early 1980s, increasing international competition and the resulting erosion in U.S. technological leadership led legislators and policymakers to conclude that existing U.S. antitrust laws and penalties were too restrictive and could be impeding the ability of U.S. companies to compete in the global marketplace. U.S. companies were at a disadvantage compared to their foreign counterparts, because of an outdated antitrust environment—designed to preserve domestic competition—that prohibited them from collaborating on most activities, including R&D.

Therefore, in 1984, restrictions on multi-firm cooperative research relationships were lifted with the passage of the National Cooperative Research Act (NCRA). (See text table 4-8.) The law was enacted to encourage U.S. firms to collaborate on generic, precompetitive research. To gain protection from antitrust litigation, NCRA requires firms engaging in research joint ventures to register them with the U.S. Department of Justice.[26] In 1993, Congress again relaxed restrictions—this time on cooperative production activities—by

[25]For example, the Industrial Research Institute's annual survey of its membership shows more than one-third of the respondents (over half in 1996) anticipating an increase in alliances and joint ventures between 1993 and 1998 (IRI 1997).

[26]According to NCRA, an RJV is "any group of activities, including attempting to make, making, or performing a contract, by two or more persons for the purpose of (a) theoretical analysis, experimentation, or systematic study of phenomena or observable facts, (b) the development or testing of basic engineering techniques, (c) the extension of investigative findings or theory of a scientific or technical nature into practical application for experimental and demonstration purposes… (d) the collection, exchange, and analysis of research information, or (e) any combination of the [above]." RJV members can be from different sectors as well as from different countries.

State R&D Issues: High Geographic Concentration and New Data on State Government R&D Support

R&D is substantially concentrated in a small number of states, a solidly entrenched configuration created by past public and private sector choices influenced by multiple economic and scientific considerations.

One-half of the $177 billion spent on R&D in the United States in 1995 was expended in six states—California, Michigan, New York, Massachusetts, New Jersey, and Texas. Add five more states—Illinois, Pennsylvania, Maryland, Ohio, and Washington—and the proportion jumps to two-thirds of the national total. (These figures do not include $6 billion of the national R&D total that could not be allocated to individual states.) One-fifth of all U.S. R&D funds, or $36 billion, was spent in California alone. In each of the next 11 leading states, R&D spending exceeded $5 billion. (See appendix table 4-55.) In contrast, the smallest 20 states together accounted for about $8 billion, or less than 5 percent of the R&D conducted nationwide in 1995.

Not coincidentally, states that are national leaders in total R&D performance also usually rank among the leading sites in industrial and academic R&D performance. (See appendix table 4-55.) Of the 11 states that lead in total R&D:

- All but Maryland ranked among the top 11 in industrial R&D performance; Florida (12th for total R&D) held the 10th slot.
- All but New Jersey and Washington ranked among the top 11 in academic R&D performance; North Carolina and Georgia (16th and 23rd for total R&D, respectively) made the short list instead.

There is somewhat more variation in the distribution of federal R&D performance. Although California ranks third, the top spots were held by Maryland and the District of Columbia, followed by Virginia. These positions reflect the concentration of federal research facilities, such as NIH, in the Washington, D.C., metropolitan area.

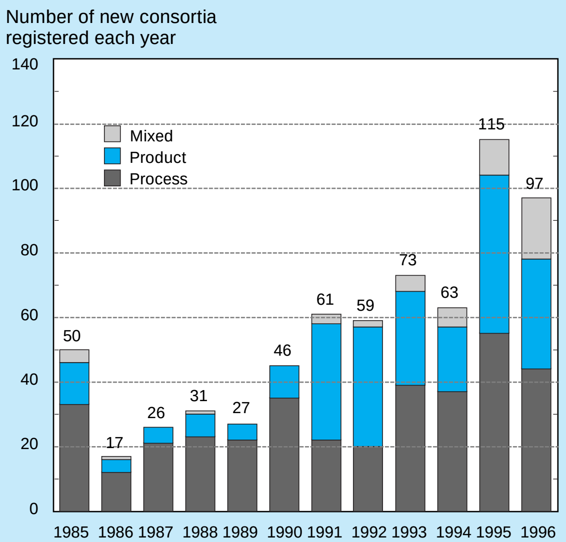
State governments have played an increasingly important role in fostering research collaborations and in helping leverage R&D funds of in-state universities and industry. They also spend an estimated $2.5 billion on R&D activities themselves (Battelle forthcoming). According to preliminary data on state government R&D spending in 1995, California, Florida, and Pennsylvania accounted for the largest funding totals. These were the only three states to individually spend more than $200 million on R&D; combined, the three spent almost $700 million. (See appendix table 4-54.) Most of these monies went to support research undertaken on our nation's campuses. Nationwide, about $400 million was spent in state government agency laboratories. As a percentage of total state funding for all services, however, states overall spent a somewhat meager 0.35 percent on R&D. In only three states—Nebraska, Kansas, and Georgia—did the R&D share exceed 1 percent of state government spending totals, according to available preliminary data.

passing the National Cooperative Research and Production Act, which enables participants to work together to apply technologies developed by their RJVs.

NCRA seems to be accomplishing its objectives. By the end of 1996, more than 665 RJVs had been registered; organizations such as Sematech have helped U.S. industries regain leadership in global markets for high-tech products like semiconductors. Although the annual number of RJV filings has increased in most years since the passage of NCRA, the largest increases were in the two most recent years, including an unprecedented 115 in 1995 and an additional 97 in 1996. (See figure 4-15.) This recent increase may reflect activity from ATP participation. (See "Advanced Technology Program.") Although data are not available on the level of resources invested in these projects, results of two investigations (Link 1996b and Vonortas 1997) revealed the following:

- The average number of members in each of the 665 RJVs is approximately 13. The average number of members in an RJV increased to a maximum of approximately 35 in 1988 and then declined in subsequent years. In 1995, the average membership was about seven, the smallest since NCRA's passage.
- The vast majority—86 percent—of RJV members are profit-making firms. Nonprofit groups, including universities and colleges, hold 10 percent of the memberships; and government agencies and organizations, 4 percent. Registered RJVs with federal participation include some of the more well-known consortia, e.g., Sematech (DOD) and the Advanced Battery Consortium (DOE).
- Most of the research conducted by RJVs has been process-oriented, although during 1991 and 1992, the number of new filings for product-oriented RJVs exceeded the number of those claiming process-oriented research. In general, the more recent data (1991-96), show less skewing toward process-oriented research than do data for 1985-90. In pre-1991 years, the RJV research focus was predominantly process-oriented.

Figure 4-15.
Growth in R&D consortia registered under the National Cooperative Research and Production Act



SOURCE: A.N. Link, "Research Joint Ventures: Patterns From *Federal Register* Filings," *Review of Industrial Organization*, Vol. 11, No. 5 (October): 617-28.

Science & Engineering Indicators – 1998

- ♦ Telecommunications is the dominant RJV technical area, accounting for about one-fifth of the total. The next largest areas are environmental[27] and transportation, each accounting for about 10 percent of the total; followed by advanced materials and energy, each at 9 percent; and software, at 7 percent.
- ♦ Few RJVs involve any type of defense-related research or research in fields where intellectual property rights tend to be well-enforced, e.g., biotechnology, medical equipment, and pharmaceuticals.
- ♦ About 30 percent of RJV members are foreign-based. The most well-represented countries (after the United States) are, in order, the United Kingdom (with 4.9 percent of the total number of entities), Japan (4.6 percent), Canada (3.6 percent), Germany (3.2 percent), and France (2.2 percent).

[27]Environmental research is probably the best example of an area in which market failure results in underinvestment in research. And, because entire industries are affected and can benefit from collaboration, it is a highly appropriate area for joint research. For example, several U.S. companies and national laboratories are involved in a collaborative effort to discover environmental processing techniques for aerospace materials. Although environmental and safety regulations raise the cost of R&D for many companies—especially those in the chemicals, petroleum, and transportation equipment industries—they also promote research that provides numerous societal benefits (Council on Competitiveness 1996).

Federal Programs

Much has been written about the Federal Government's changing role in the development and deployment of new technologies. The postwar "spinoff" model, in which certain industries (e.g., aerospace, computer, and biotechnology) built much of their competitive strength off the government's investment in R&D, has given way to a new model—one in which evidence is pointing to greater government benefits derived from the commercial sector's work in technology development than the other way around. For example, technologies in the software, computer, semiconductor, telecommunication, advanced materials, and manufacturing areas that are pushing the state of the art in U.S. military hardware and equipment were mostly developed in the private sector.

The public sector's evolving role in S&T—and the upsurge in international competition faced by U.S. firms—has led to another change in which the government is taking on the role of "partner" rather than merely customer in federally supported S&T programs. Since 1980, several new programs have come into being, all with the major goal of having the government partner with the private sector to strengthen the U.S. position in international markets for high-tech goods and services. This new approach to technology development and deployment includes the following guideposts:

- ♦ Economic (i.e., commercial potential) as well as technical considerations should play a role in selecting projects to receive public sector support.
- ♦ Cost-sharing is crucial, because it ensures that private sector partners have a stake in the R&D's outcome and success.
- ♦ The private sector should have a major role in project selection and management, because economic growth and jobs—the main benefits of R&D commercialization—are the role of the private sector (U.S. DOC/OTP 1996).

It should be noted that although these new public-private partnerships account for only a small portion of total federal R&D investment in technology, they seem to have broad, widespread support within the private sector.[28]

Technology Transfer Activities

Technology transfer activities became an important mission component of federal laboratories in the late 1980s. Of course, some agencies, including USDA's agricultural research

[28]Support for these programs has been documented by the National Association of Manufacturers, Industrial Research Institute, and Semiconductor Equipment and Materials International (Council on Competitiveness 1996). In addition, a GAO study of manufacturing extension programs found high levels of private sector satisfaction with these programs (U.S. GAO 1995). Another survey revealed a high level of satisfaction among industry officials who had used federal laboratories: e.g., 89 percent of respondents considered their interactions to be a good use of their companies' resources. Even in cases where the costs exceeded the benefits, many industry officials still expressed high levels of satisfaction (Bozeman, Papadakis, and Coker 1995).

experiment stations and NASA's civilian aeronautics programs, have always shared their research with the private sector.[29] But after Congress passed several laws, including the Stevenson-Wydler Technology Innovation Act (1980), the Federal Technology Transfer Act (1986), and the National Competitiveness Technology Transfer Act (1989), other agencies were given the go-ahead to open their laboratory doors. (See text table 4-8.) In addition, because of budget cutbacks and a decline in defense-related work, federal laboratories have an even greater incentive to stretch their resources through partnering with industry, academia, and state organizations to work on commercially inspired initiatives.[30]

Growing Public-Private Cooperation

Evidence of growing cooperation between federal laboratories and private sector entities can be seen in the number of cooperative research and development agreements (CRADAs) executed in the past few years.[31] These formal agreements were created by Congress under "the belief that federal laboratories hold valuable technological assets and that those assets should be used not only for pursuing an agency's mission but also to improve the competitive position of U.S. firms" (U.S. DOC/OTP 1996). Thus, the purpose of CRADAs is to facilitate and expedite the transfer of technology from federal laboratories to the private sector by enabling private sector researchers to gain access to and take advantage of government R&D expertise and resources.

Between 1992 and 1995 (the most recent year for which data are available), 3,512 CRADAs were executed. The annual number of new CRADAs more than doubled between 1992 and 1994, going from just over 500 to more than 1,100. However, the annual number of new agreements fell the next year to just over 1,000. (See text table 4-9.)

Text table 4-9.
Number of new cooperative R&D agreements executed, by agency

Agency	Total	1992	1993	1994	1995
Total	3,512	502	877	1,130	1,003
Agriculture	270	41	103	72	54
Commerce	412	86	147	97	82
Defense	1,001	131	201	298	371
Energy	1,553	160	367	564	462
Environmental Protection	43	20	5	10	8
Health & Human Services	136	53	25	36	22
Interior	61	3	15	39	4
Transportation	36	8	14	14	0

SOURCE: Technology Publishing Group, *The 1996 CRADA Handbook: Federal Government Cooperative Research and Development Agreements Executed in 1995* (Washington, DC: 1997).

Science & Engineering Indicators – 1998

During the 1992-95 period, DOE executed the largest number of new CRADAs (1,553), followed by DOD (1,001), DOC (412), and USDA (270). Interestingly, every agency except DOD reported a lower number of new CRADAs executed in 1995 than in the previous year. (See text table 4-9.) Government agencies seem to be backing away from these agreements, in contrast to the early 1990s when there was a strong push for them (Larson 1997). DOE had the largest absolute reduction in new CRADAs, as recent budget cutbacks left decreased support for new agreements and prompted termination and scaling back of existing ones, especially at DOE weapons laboratories (Technical Insights 1996).

About 75 percent—or 749—of the 1,003 1995 CRADAs were executed by individual industrial firms; consortia and nongovernment organizations were responsible for 87; universities, 86; and state and local governments, 10.

The total number of private sector partners in the 1995 agreements was 688; 124 organizations executed two or more CRADAs during 1995.

The U.S. Council on Automotive Research, which represents industry's role in the Clean Car Agreement between the Clinton Administration and the "big three" auto makers (and is responsible for R&D associated with the Partnership for a New Generation of Vehicles),[32] executed 32 new CRADAs in 1995, far more than any other private sector partner. (See figure 4-16.) General Motors was a distant second with 15, followed by Dupont with 8, and the University of Maryland with 6. Four companies—AT&T, Chevron, Martin Marietta (now Lockheed Martin), and SI Diamond Technologies—each executed five agreements; and seven organizations executed four.

[29]For example, NASA has played a lead role in the development of new technologies in propulsion and aerodynamics that have made crucial contributions to the success of the commercial aircraft industry.

[30]According to one survey, companies' major incentives for working with federal laboratories are leveraging R&D, gaining access to federal expertise and facilities, and developing business opportunities—in that order. Respondents also noted that informal types of interaction were the most frequent and effective. "There is a danger that too much emphasis will be placed on evidence of tangible economic payoffs (CRADAs [cooperative research and development agreements], licenses) as measures of success, with insufficient recognition of the value to companies of access to state-or-the-art knowledge and equipment" (U.S. DOC/OTP 1996).

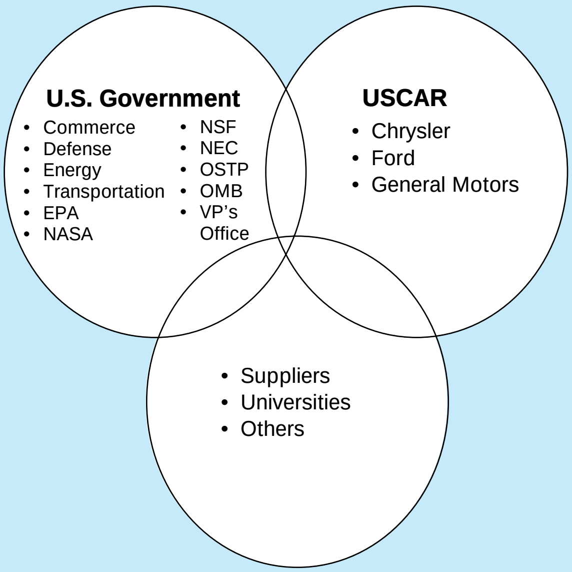
As an example of the growing interaction between federal laboratories and industry, member companies have hosted senior scientists and engineers from Los Alamos, under a special Industrial Research Institute program (Larson 1997a).

On the other hand, pharmaceutical and biotechnology companies have historically been reluctant to work directly with government (NIH) laboratories because of intellectual property and pricing issues (the government reserves the right to control the price of products exclusively licensed by pharmaceutical companies), despite passage of the Technology Transfer Act of 1986, which authorized federal intramural laboratories—including NIH—to offer CRADA partners preference in licensing any intellectual property developed under the CRADA.

[31]Most of the information in this section was obtained from Technology Publishing Group (1997).

[32]The Partnership's purpose is to create a zero-pollution, 80-mile-per-gallon automobile marketable early in the next century.

Figure 4-16.
Partnership for a New Generation of Vehicles relationships



NOTE: EPA = Environmental Protection Agency; NASA = National Aeronautics and Space Administration; NEC = National Economic Council; OMB = Office of Management and Budget; OSTP = Office of Science and Technology Policy; USCAR = U.S. Council on Automotive Research.

SOURCE: Section 10, PNGV Program Plan, July 1994.

Science & Engineering Indicators – 1998

Federal Partnerships With Industry

Two federal technology partnership programs were started in the 1990s: DOC's Advanced Technology Program and DOD's Technology Reinvestment Project (TRP). The purpose behind both programs was to spur the development and deployment of high-risk enabling technologies through an industry-driven, cost-sharing process, whereby industry proposed the research and supplied at least half the funding. Of the two programs, only ATP survives, and its budget was sharply reduced in 1996.

Advanced Technology Program. ATP was designed "to act as a catalyst for the development of high-risk technologies that have broad applications and the potential for large economic impact" (U.S. DOC/OTP 1996), but few federal R&D programs have sparked as much controversy as this one. Neither criticism nor praise for ATP are in short supply. Although the program came into being (as part of the Omnibus Trade and Competitiveness Act of 1988) with substantial bipartisan support, it has come under attack in recent budget debates. The Republican-led Congress has been eager to zero-out a program that provides federal research assistance to corporations.[33] ATP's survival is largely attributable to strong backing from the Clinton Administration and support from the high-tech business community. Although congressional efforts to eliminate the program have yet to succeed, ATP's budget was cut by a third in 1996. Funding remained level in FY 1997 at $218 million, almost 40 percent of NIST's $581 million in appropriated funding.[34]

Between 1990 and 1996, more than $2 billion in public and private funds were invested in a total of 288 ATP projects—184 awards to single applicants and 104 to joint ventures. (See appendix table 4-36 and figure 4-17.) Only about 10 percent of ATP proposals receive funding.

The government's share of ATP is closing in on $1 billion, while private support is slightly above the billion-dollar mark. The 184 single-applicant projects have a total funding level of $600 million, with ATP funds making up slightly more than half that amount and companies providing the remaining portion. The average award size across single applicants and joint ventures is $3.4 million.[35] The 104 joint ventures have a total funding level of $1.4 billion—with just over half of those monies provided by private sector participants.

ATP runs two kinds of competitions—general and focused. Companies or consortia can submit proposals for support in any technology area(s) in the general competitions, while the focused competitions are for specific technologies. The funding split between the two types of competitions is about 40/60 (through 1996). Proposals are selected through a peer review process and are judged on both their technical merit and their potential for commercial success.[36]

ATP has undergone extensive evaluation. NIST-funded case studies and surveys conducted a few years after the program's inception revealed ATP's success in fostering high-risk research that would not have been attempted otherwise. Other benefits were reduced time-to-market, accelerated R&D time tables, job creation, and the formation of strategic R&D alliances. The full economic impact of the program will be examined in future studies, as more projects complete the R&D phase and reach commercial development (U.S. DOC 1995).

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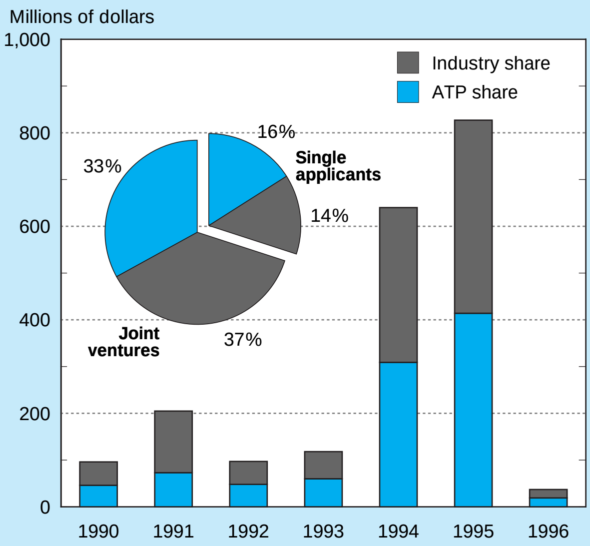
[33]Because ATP is a source of federal funding for technology development that benefits the private sector—and the grants do not have to be repaid or the research results shared—many consider ATP to be a form of "corporate welfare." In the opposite camp are those who believe government has an important role to play in fostering industrial competitiveness by funding research that would not happen without public support. According to one advocate, "ATP plugs a gap that used to make U.S. research vulnerable to foreign competition." The industry official was referring to the perspective that the Federal Government's traditional method of funding research by providing support to academic institutions enables foreign companies to take advantage of the research results at little cost to them (MSNBC 1997).

[34]A $7 million rescission from the $225 million appropriated for ATP made the actual FY 1997 funding level $218 million.

[35]The largest award made was $31.5 million, to a joint venture. Single applications are limited to $2 million (MSNBC 1997).

[36]About 45 ATP projects are classified as "completed," which means the ATP-funded R&D has been done. Several have produced finished products already in the marketplace (MSNBC 1997).

Figure 4-17.
Advanced Technology Program funding



See appendix table 4-36.

Science & Engineering Indicators – 1998

A 1995 GAO study of ATP gave the program a mixed review.[37] While it found the program to be meeting some of its goals—including fostering the formation of joint ventures and facilitating the funding of risky, precompetitive research—the findings also suggested that ATP is funding "research projects that would have been funded by the private sector as well as those that would not" (U.S. GAO 1996b). Not surprisingly, this conclusion provided ammunition for both opponents and proponents of the program (Long 1996).

In response to the congressional criticism, the Secretary of Commerce ordered a report on ATP in March 1997 (U.S. DOC 1997). The following recommendations from this evaluation are being implemented:

- Project evaluation criteria will be modified to put more emphasis on joint ventures and consortia and less on individual applications from large companies.
- The cost-share ratio for large companies applying as single applicants will be increased to a minimum of 60 percent.
- Linkages with the private sector venture capital community will be strengthened.
- State participation through state-sponsored business and technology support programs will be encouraged.

Defense-Related Programs. Defense policy has undergone major changes during the 1990s. Not only has the cessation of Cold War hostilities had a major impact on the size and allocation of the defense budget, but economic considerations and technological advancements are also affecting the U.S. approach to national security. While base closings grab front-page coverage, the less sensational aspects of defense downsizing—namely the paring and reshaping of programs that support scientific research and new technology development—also are being addressed.

During the 1990s, DOD has been pursuing a "dual-use" strategy; i.e., it has been providing financial support to the private sector to develop and deploy technologies likely to have both commercial and military applications. For example, semiflat-panel displays, semiconductors, and smart-weapons technology all have applications in both the commercial and military sectors. The benefits to the government from this approach are assumed to be reduced procurement costs and faster weapons development and improvement cycles.

However, the dual-use approach has attracted a considerable amount of controversy. Opponents contend that it represents an attempt at industrial policy inappropriate for the government in a free-market system. Lack of congressional support led to the demise in 1995 of TRP—the centerpiece of dual-use efforts earlier in the decade.[38]

TRP's successor is called the Dual-Use Applications Program (DUAP). The mission of DUAP is to develop prototypes for and demonstrate new approaches to incorporating commercial research, technology, products, and processes into military systems. The main difference between this and previous dual-use efforts is that the armed services will play a major role by selecting the technology areas they wish to emphasize and support. The FY 1997 DOD appropriation was $135 million to begin funding two DUAP initiatives:

1. The Science and Technology Initiative, with an FY 1997 budget of $85 million. The money will be used to fund projects to develop militarily useful, commercially viable technology. One-quarter of the funding for each project will come from the S&T program, one of the three service branches will supply another quarter, and the remaining half will come from the company performing the work.
2. The Commercial Operations Support Savings Initiative (COSSI), with an FY 1997 budget of $50 million. The money will be used to develop prototypes that leverage commercial R&D to improve the performance of military systems and to decrease operations and support costs. Thirty projects (10 Army, 14 Navy, and 6 Air Force) out of

[37] GAO surveyed all winning and "near-winning" applicants during ATP's first four years; the response rate was 100 percent.

[38] TRP competitions were held in 1993, 1994, and 1995. The purpose of the program was to fund public-private partnerships to develop technologies for new products and processes meeting both military and commercial needs. It was managed by the Defense Advanced Research Projects Agency, with participation by several other federal agencies. All federal funding, however, was provided by DOD, with industry providing an equal or higher share of financial support for each project. The most recent data show DOD spending to be approximately $700 million on a total of 131 projects awarded TRP support. Focus areas for the 1995 winners were affordable advanced controls technologies, biological sensors and multi-organ diagnostic screening, digital wireless communications and networking systems, microelectromechanical systems applications, operations other than war/law enforcement, and small precision optics manufacturing technology. (See "Independent Research and Development Provides Additional Defense Funding.")

81 proposals were selected for funding in the 1997 competition.[39]

There is also 1997 funding for a third dual-use program. The Commercial Technology Insertion Program will provide approximately $7.5 million in FY 1997 to adapt a commercial signal processing technology to the APG-63 Radar and to qualify microelectromechanical sensors for use in military systems.

Other Federal Cooperative Technology Programs. Other examples of government-industry-academic collaborations include those made under the NSF-funded Science and Technology Centers and Supercomputer Centers and the Grant Opportunities for Academic Liaison with Industry Program. These programs stimulate interactions among industry, academia, and government, mostly through personnel exchanges—which are often identified as the most effective way of transferring knowledge across sectors.

Cross-cutting Administration initiatives have also promoted inter-sectoral collaboration. For example, since 1991, the federal High Performance Computing and Communications (HPCC) Program has been responsible for long-term R&D in advanced computing, communications, and information technologies. The Next Generation Internet, which is part of the HPCC initiative, is bringing together users, network providers, and researchers from all sectors to develop new networks and advanced applications technologies, including new multimedia services for homes, schools, and businesses. (See chapter 8.)

International Comparisons of National R&D Trends

Absolute levels of R&D expenditures are indicators of the breadth and scope of a nation's S&T activities.[40] The relative strength of a particular country's R&D effort is further indicated through comparison with other major industrialized countries. This section provides such comparisons of international R&D spending patterns. It examines absolute and relative expenditure trends, contrasts performer and source structural patterns, reviews the foci of R&D activities, and looks at government priorities and policies. While R&D performance patterns by sector are quite similar across countries, national sources of support differ considerably. Foreign sources of R&D have been increasing in practically all countries.

U.S. leadership in terms of financial investment in R&D compared to other countries' remains largely unchanged from a decade ago, with the U.S. R&D total nearly equal to that of the next six largest performers combined. Virtually all of the major R&D-performing countries experienced a slowing in the growth of R&D funds in the early 1990s, and most continue to feel the funding pinch. The United States and Japan may be exceptions, each reporting significant increases in R&D activity for 1995.

Total Research and Development Trends

Absolute Levels

Worldwide Distribution of R&D. The worldwide distribution of R&D performance is concentrated in several industrialized nations.[41] Of the approximately $410 billion in 1995 R&D expenditures estimated for the 28 Organisation for Economic Co-operation and Development (OECD) countries, 90 percent is expended in just seven (OECD 1997b). These estimates are based on reported R&D investments (for both defense and civilian projects) converted to U.S. dollars with purchasing power parity (PPP) exchange rates. (See appendix table 4-2.) Although PPPs technically are not equivalent to R&D exchange rates, they better reflect differences in countries' laboratory costs than do market exchange rates (MERs). (See "Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data.")

The United States accounts for roughly 44 percent of the industrial world's R&D investment total and continues to outdistance, by more than 2 to 1, the research investments made in Japan, the second largest R&D-performing country. Not only did the United States spend more money on R&D activities in 1995 than any other country, but it also spent almost as much by itself as the rest of the major industrialized "Group of Seven" (G-7) countries combined—Japan, Germany, France, the United Kingdom, Italy, and Canada. (See appendix table 4-42.) In only four other countries—the Netherlands, Australia, Sweden, and Spain—do R&D expenditures exceed 1 percent of the OECD R&D total (OECD 1997b).

Worldwide Slowing of R&D Spending. In 1985, spending in non-U.S. G-7 countries was equivalent to 91 percent of U.S. R&D expenditures that year, climbing steadily to peak at 107 percent of the U.S. total in 1992. A worldwide slowing in R&D performance—more pronounced in other countries than in the United States—lowered 1995 R&D spending in these six countries to 101 percent of the U.S. total. (See figure 4-19.)

Total R&D expenditures stagnated or declined in each of the largest R&D-performing countries in the early 1990s. (See figure 4-20.) Indeed, for more than a decade, these G-7 countries have displayed similar aggregate R&D trends: substantial

[39]COSSI agreements will also allow prime contractors to apply their independent R&D funds as a cost-sharing mechanism. See "Independent Research and Development Provides Additional Defense Funding."

[40]The R&D data presented here for the major industrialized countries are obtained from reports to the Organisation for Economic Co-operation and Development (OECD), which is the most reliable source of such international comparisons. A fairly high degree of consistency characterizes the R&D data reported by OECD, with differences in reporting practices among countries affecting their R&D/GDP ratios by no more than an estimated 0.1 percentage point (ISPF 1993). Although R&D data for non-OECD countries are not as widely available and statistically consistent, many of the less developed and former communist countries have made steady improvements over the past few years to make their R&D statistics more internationally comparable. Several such statistics are referenced within this chapter.

[41]Some developing countries have greatly expanded the level of national resources they devote to civilian research efforts; nonetheless, the overall financial impact of their efforts is small compared with those of large industrialized countries. For example, South Korea—a country that has made considerable strides in expanding its domestic R&D investment—spends about $7 billion annually, a figure equivalent to about 3 percent of the U.S. total. For a review of Korea's recent efforts to strengthen its domestic science and technology base, see OECD (1996b).

Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data

Comparisons of international statistics on R&D are hampered by the fact that countries' R&D expenditures are denominated, obviously, in their home currencies. Two approaches are commonly used to normalize the data and facilitate aggregate R&D comparisons. The first method is to divide R&D by GDP, which results in indicators of relative effort according to total economic activity. The second method is to convert all foreign-denominated expenditures to a single currency, which results in indicators of absolute effort. The first method is a straightforward calculation, but permits only gross national comparisons. The second method permits absolute-level comparisons and analyses of countries' sector- and field-specific R&D investments, but entails first choosing an appropriate currency conversion series.

Because, for all practical purposes, there are no widely accepted R&D-specific exchange rates, the choice is between market exchange rates and purchasing power parities. These are the only series consistently compiled and available for a large number of countries over an extended period of time.

At their best, MERs represent the relative value of currencies for goods and services that are traded across borders; that is, MERs measure a currency's relative international buying power. But sizable portions of most countries' economies do not engage in international activity, and major fluctuations in MERs greatly reduce their statistical utility. MERs also are vulnerable to a number of distortions—e.g., currency speculation, political events such as wars or boycotts, and official currency intervention—that have little or nothing to do with changes in the relative prices of internationally traded goods.

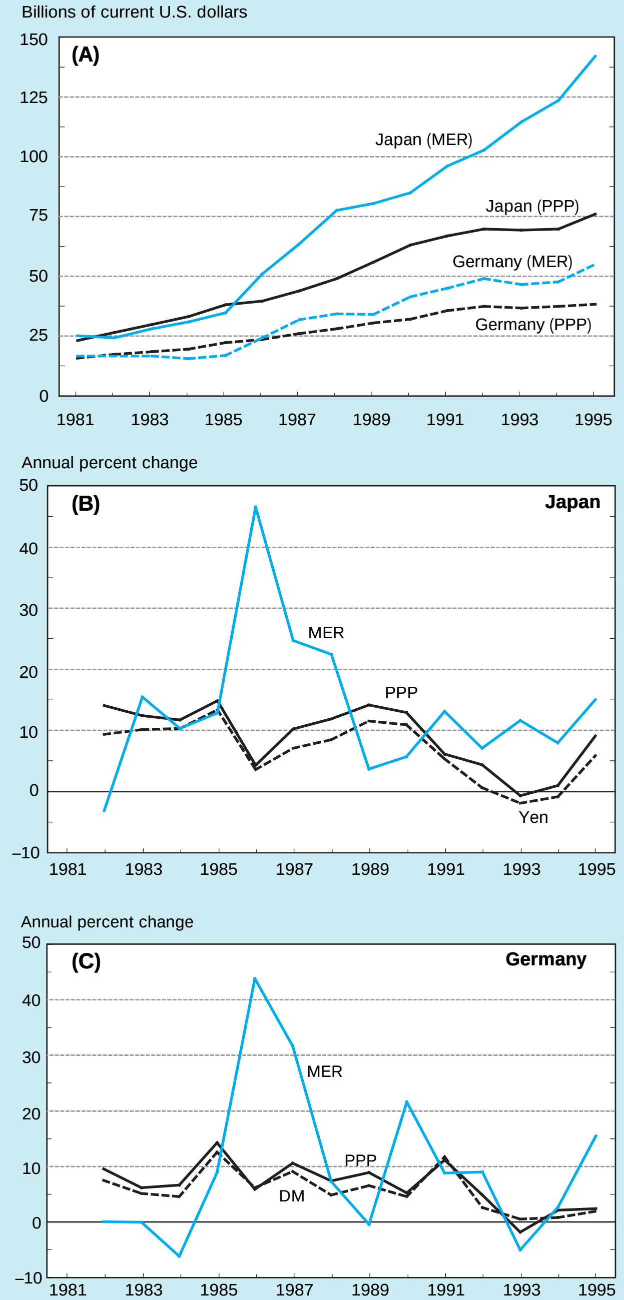
For these reasons, an alternative currency conversion series—PPPs—has been developed (Ward 1985). PPPs take into account the cost differences across countries of buying a similar basket of goods and services in numerous expenditure categories, including nontradables. The PPP basket is therefore representative of total GDP across countries. When applied to current R&D expenditures of other major performers—Japan and Germany—the result is the same: PPPs result in a substantially lower estimate of total research spending than do MERs, as shown in figure 4-18 (A). For example, Japan's R&D in 1995 totaled $76 billion based on PPPs and $142 billion based on MERs. German R&D was $38 billion and $55 billion, respectively. U.S. R&D was $183 billion in 1995.

PPPs are the preferred international standard for calculating cross-country R&D comparisons and are used in all official OECD R&D tabulations. Although there is considerable difference in what is included in GDP-based PPP items and R&D expenditure items, the major components of R&D costs—fixed assets and the wages of scientists, engineers, and support personnel—are more suitable to a domestic converter than to one based on foreign trade flows. Exchange rate movements bear little relationship to changes in the cost of domestically performed R&D. This point is clearly displayed in figure 4-18 (B) and (C). When annual changes in Japan's and Germany's R&D expenditures are converted to U.S. dollars with PPPs, they move in tandem with such funding denominated in their home currencies. Changes in dollar-denominated R&D expenditures converted with MERs exhibit wild fluctuations unrelated to the R&D purchasing power of those investments. MER calculations indicate that, between 1982 and 1995, German and Japanese R&D expenditures each increased in three separate years by 20 percent or more. In reality, nominal R&D growth never exceeded 14 percent in either country during this period.

Worse, MER calculations often result in the wrong direction of implied R&D change. Japan reported reductions in nominal yen R&D in 1993 and 1994, but the use of MERs resulted in positive growth rates of 12 and 8 percent, respectively. PPP-denominated R&D was appropriately negative and flat those two years. Conversely, Japan's MER-denominated R&D expenditures declined in 1982, as did Germany's in 1983, 1984, 1989, and 1993. Yet the home currency-denominated R&D expenditures showed positive changes in each of those years. The use of MERs here is obviously inappropriate: PPP calculations result in generally positive annual R&D expenditure changes that are always considerably closer to the countries' actual funding patterns.

inflation-adjusted R&D growth in the early 1980s, followed by a general tapering off in the late 1980s, then leveling off or declining real R&D expenditures into the 1990s. For most of these countries, economic recessions and general budgetary constraints slowed both industrial and government sources of R&D support; these factors contributed to the major reversal of positive R&D trends in the United States and Japan, where inflation-adjusted R&D spending declined for three consecutive years beginning in 1992. The same general pattern is true for the United Kingdom and Italy, where real growth in the 1980s gave way to declining R&D expenditures, taking into account overall inflation. Unlike in the United States and Ja-

Figure 4-18.
Japanese and German R&D expenditures and annual changes in R&D estimates

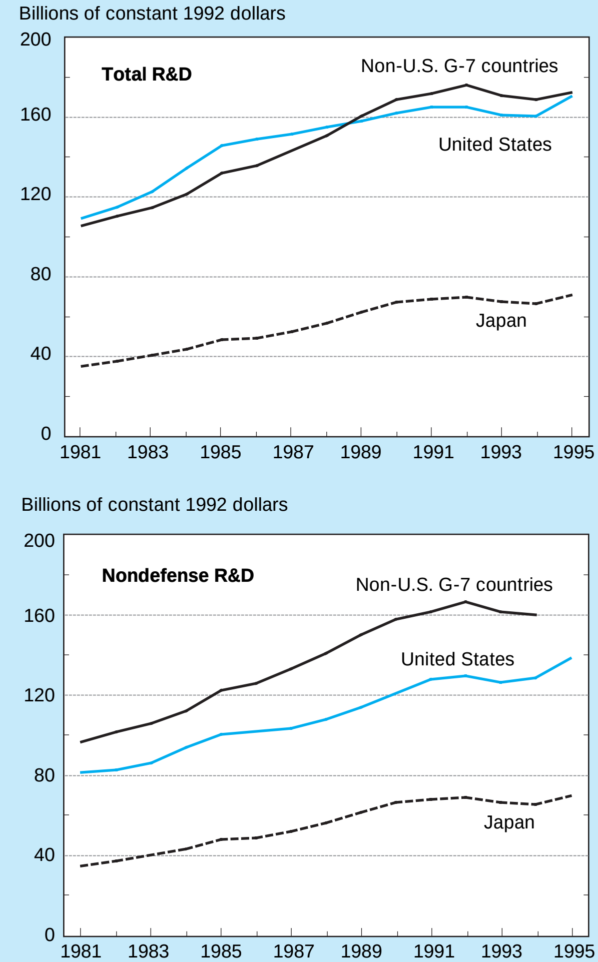


NOTE: DM = deutsche mark; MER = market exchange rate; PPP = purchasing power parity.

See appendix tables 4-2 and 4-42.

Science & Engineering Indicators – 1998

Figure 4-19.
U.S. and other G-7 countries' R&D expenditures



NOTE: The non-U.S. G-7 countries are Japan, Germany, France, the United Kingdom, Italy, and Canada.

See appendix tables 4-42 and 4-44.

Science & Engineering Indicators – 1998

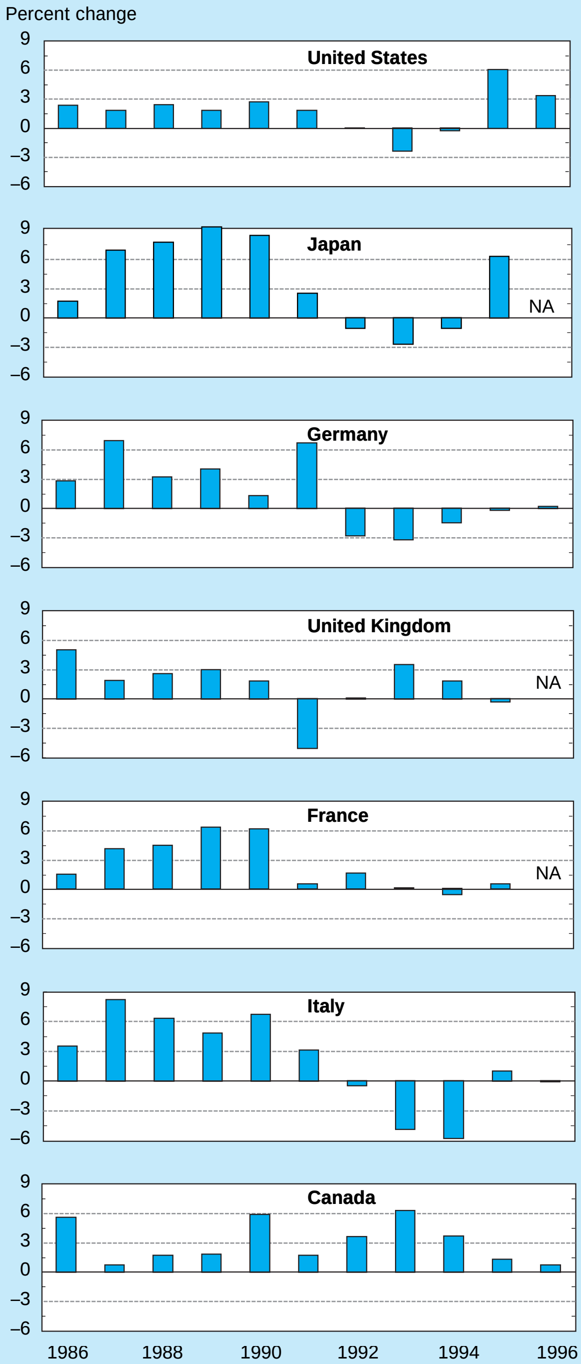
pan, however, R&D spending in these countries has not recovered to previous levels.

Government Cutbacks in Defense-Related R&D. Additionally, changes in the world's geopolitical climate have led to cutbacks in government support for defense-related R&D. Such reductions, in turn, have slowed reported national R&D growth patterns in some countries, most notably in the United States, the United Kingdom, and France. For Germany, the integration of the former East German S&T system into the S&T system of West Germany's market economy resulted in an apparent jump in the nation's R&D effort in 1991; it has since been scaled back as a result of the restructuring and closing of inefficient, inappropriate, and redundant research institutions (Government of the Federal Republic of Germany 1993). To date, up to one-third of all former East Germany's R&D institutions have been closed.

Ratio of R&D to GDP

Decreased Ratios in G-7 Countries. The drop in Germany's total R&D effort is indicated by recent trends in its R&D/GDP ratio, one of the most widely used indicators of a country's commitment to growth in scientific knowledge and

Figure 4-20.
Rates of change in total R&D spending for selected countries



NOTES: The inflation-adjusted R&D expenditures reflected in this graph are denominated in foreign currencies deflated by the countries' own GDP price deflators, and therefore are not distorted by exchange rate conversions. NA is not available.

See appendix table 4-42. *Science & Engineering Indicators – 1998*

technology development. (See figure 4-21.) In Germany, the ratio has fallen from 2.9 percent at the end of the 1980s, before reunification, to its current level of 2.3 percent. This pattern is not, however, restricted to Germany. In fact, the latest R&D/GDP ratio in each of the G-7 countries is no higher now than it was at the start of the 1990s. For example, in the United Kingdom and France, R&D/GDP ratios appear to have drifted back from recent peaks to 2.1 and 2.3 percent, respectively. In Italy and Canada, which also have faced economic and budgetary constraints, the R&D/GDP ratios leveled off at about 1.1 percent and 1.6 percent, respectively.

In the United States, R&D's share of GDP similarly declined from 2.7 percent in 1991 to an estimated 2.4 percent in 1994, before climbing back to an estimated 2.6 percent in 1997. As detailed earlier in the chapter, most of the increase in R&D is due to increased support in the industrial sector, primarily by electrical equipment and transportation equipment companies. (See "Industrial Research and Development.") Similarly in Japan, the R&D/GDP ratio fell from 2.9 percent in 1990 to 2.6 percent in 1994, before rising to 2.8 percent in 1995.[42] Both industry and government were responsible for renewed vigor in Japan's R&D spending, with Japan's 1996 Science & Technology Plan suggesting a doubling (in constant yen) of the government's R&D investment by the year 2000 (NSF 1997d).[43]

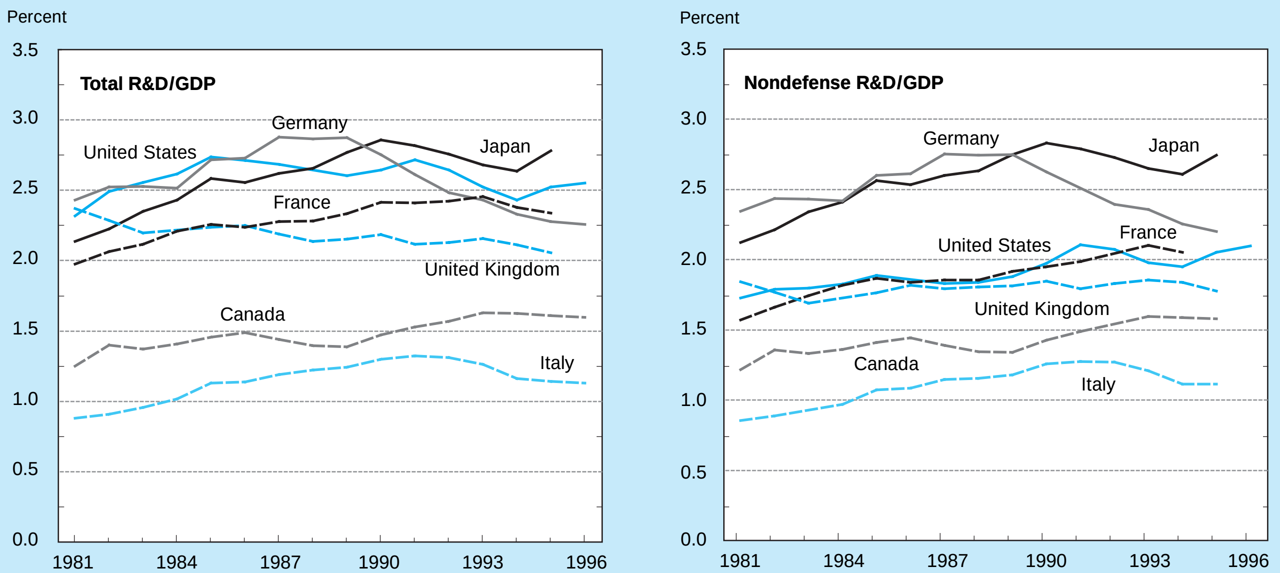
Severe R&D Downsizing Also in Smaller Countries. The likely reversal of funding trends in the United States and Japan notwithstanding, the recent slowdown in R&D spending has not been confined to OECD's largest industrialized countries. R&D growth during the 1990s in many of the smaller or less technologically advanced European countries has been slower than the growth reported for the 1980s. This is particularly true among Eastern European countries and the former Soviet Union, where market economy transitions have necessitated severe market and industrial adjustments, accompanied by even more severe downsizing of R&D activities (European Commission 1994).

The R&D/GDP ratios shown for Russia and several of the former communist states (see figure 4-22) clearly show the overall decline in those countries' indigenous R&D capabilities since the collapse of the Soviet Union. More recent efforts to stabilize the R&D infrastructure are also apparent in the figure. Poland, Hungary, and the Russian Federation each expend roughly 0.75 percent of GDP on R&D activities; for

[42]The R&D data reported here for Japan generally reflect the official Japanese statistics adjusted by OECD to make them more comparable with international standards. In Japan, data for R&D personnel are expressed as number of people working mainly on R&D rather than as full-time equivalents. Consequently, R&D labor cost data—and therefore total R&D expenditures—are overestimated by international standards. Based on estimates obtained from recent Japanese studies, OECD reports adjusted Japanese R&D totals that are about 15 percent lower than the official R&D series. For example, the adjusted Japan R&D/GDP ratios reported here are 2.1 percent for 1981, 2.9 percent for 1990, and 2.8 percent for 1995. The unadjusted ratios are 2.3 percent for 1981, 3.0 percent for 1990, and 3.0 percent for 1995.

[43]Although growth in Japanese R&D spending was strongly positive in 1995, more recent problems of overall economic stagnation may foretell another slowing in R&D spending, as was seen in 1992-94, at least by Japanese industrial firms.

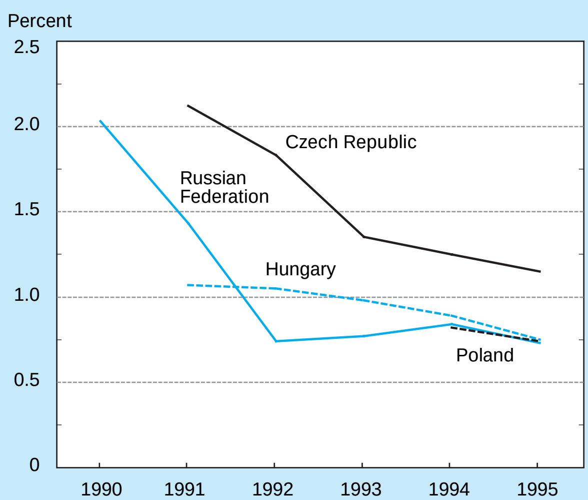
Figure 4-21.
R&D as a percentage of GDP for G-7 countries



See appendix tables 4-42 and 4-44.

Science & Engineering Indicators – 1998

Figure 4-22.
R&D as a percentage of GDP for the Russian Federation and Central European countries



NOTE: Data are not available before 1991 for the Czech Republic and Hungary and before 1994 for Poland.

See appendix table 4-43. *Science & Engineering Indicators – 1998*

the Czech Republic, the R&D/GDP ratio was about 1.2 percent in 1995.

Notably, whether the overall economy has been growing strongly (as in Poland), modestly (as in Hungary and the Czech Republic), or poorly (as in Russia), R&D expenditures have fallen as a share of GDP. Although these governments appear strongly motivated to make institutional changes that foster private sector S&T investments, total R&D expenditures continue to falter. This circumstance is partly explained by looking at the composition of industrial activity in these countries. The more successful examples of private sector growth occur in industrial sectors where small businesses often perform better than larger state-owned enterprises (OECD 1996b). Yet such firms seldom have access to resources on a scale large enough to permit heavy R&D investments. Conversely, the larger state-owned enterprises have been more concerned with needed restructuring and downsizing than with expanding their R&D expenditures.

Effects on R&D of Russia's Economic Restructuring. As recently as 1990, R&D accounted for about 2 percent of the USSR's GDP, with about 40 percent of that amount expended on defense-related activities (Gohkberg, Peck, and Gacs 1997).[44] Indeed, the most advanced aspects of Soviet R&D efforts were undertaken in state-owned enterprises devoted to national security; much of the remaining R&D was performed in other large public industrial institutions in applied research fields that overlapped defense concerns. Most of the basic research was and continues to be in engineering fields.

The introduction of a market economy to Russia brought about drastic economic restructuring that saw a sharp fall in the dominance of state-owned enterprises as well as shrinkage in real GDP, down 38 percent from 1991 to 1995. These trends, in turn, brought about major R&D downsizing, with real R&D expenditures in 1995 less than one-fifth of 1990

[44] R&D data for the Russian Federation are taken from Centre for Science Research and Statistics surveys designed to collect such statistics in accordance with OECD international standards.

levels and with an R&D/GDP ratio of about 0.7 percent. Reflecting the lack of core budgets, entire research institutes have been closed—including many well-equipped laboratories of the former military-industrial complex—and an estimated 43 percent of all researchers from 1990 to 1994 left their government R&D laboratories for the commercial sector or retirement or for other reasons, including emigration.

Defense now accounts for about 26 percent of Russia's total R&D, a share comparable to that in the United States. According to statistics released by the Russian Ministry of Science and Technological Policy, overall government R&D budget appropriations now represent about 0.74 percent of GDP, three-fifths of which goes for civilian R&D. In 1991, the comparable figures were 1.85 percent of GDP, one-half of which was civil (CSRS 1997). In real terms, the Russian government's 1994 R&D financing was only one-fourth of that in 1991. As a consequence, business enterprise financing has become increasingly important in the Russian Federation, as has R&D funding from foreign research centers, commercial companies, and international organizations.

Nondefense R&D Trends

Absolute Levels

The policy focus of many governments on economic competitiveness and commercialization of research results has shifted attention from nations' total R&D activities to nondefense R&D expenditures as indicators of scientific and technological strength.[45] Indeed, conclusions drawn about a country's relative standing may differ dramatically depending on whether total R&D expenditures are considered or whether defense-related expenditures are excluded from the totals. In absolute dollar terms, the U.S. international nondefense R&D position is still considerably more favorable than that of its foreign counterparts, but not nearly as dominant as when total R&D expenditures are compared. U.S. civil R&D remains twice that of Japan's, but the non-U.S. G-7 countries' combined total is 18 percent more than nondefense R&D expenditures in the United States alone.

Between 1982 and 1990, growth in U.S. nondefense R&D spending was fairly similar to growth in other industrial countries, save Japan, whose nondefense R&D expenditure growth was notably faster. Thus, as an equivalent percentage of the U.S. nondefense R&D total, comparable Japanese spending jumped from 45 percent in 1982 to 55 percent in 1990. (See appendix table 4-44.) During this period, Germany's annual spending equaled 26 to 29 percent of U.S. nondefense R&D spending, while France's annual spending was equivalent to 17 to 18 percent, and the United Kingdom's annual spending fluctuated narrowly between 15 and 16 percent of the U.S. total.

Since 1990, the worldwide slowing in R&D spending and the subsequent apparent recovery in the United States has narrowed the gap between U.S. nondefense R&D spending and that in the other G-7 countries. In 1995, the combined nondefense R&D spending in these six countries equaled $163 billion (in constant PPP dollars), compared with $138 billion (constant dollars) in the United States. Japanese and German spending relative to U.S. spending declined to 50 and 25 percent, respectively.

Ratio of Nondefense R&D to GDP

In normalizing for the size of these economies, the relative position of the United States is slightly less favorable. Japan's nondefense R&D/GDP ratio (2.7 percent) considerably exceeded that of the United States (2.1 percent) in 1995, as it has for years. (See figure 4-21 and appendix table 4-44.) The nondefense R&D ratio of Germany (2.2 percent and declining since a 1989 peak of 2.7 percent) and France (2.1 percent) roughly matched the U.S. ratio; the ratios of the United Kingdom (1.8 percent), Canada (1.6 percent), and Italy (1.1 percent) were somewhat lower. As with total R&D ratios, the nondefense R&D/GDP shares were level or falling in the United States, Germany, and Japan during the early 1990s.

R&D Funding by Source and Performer

By Performer

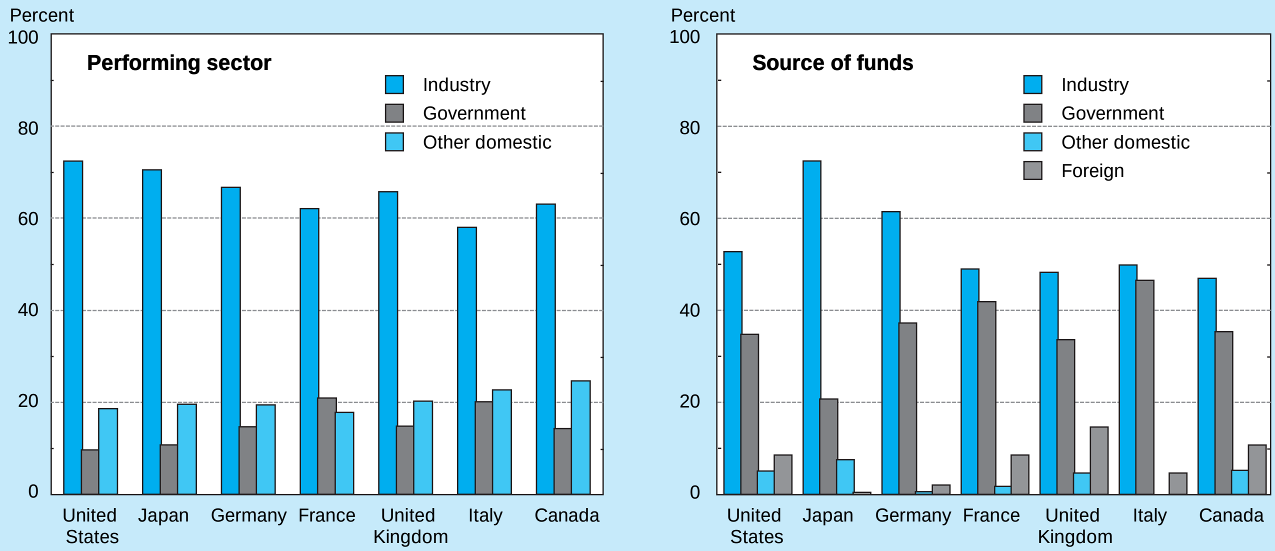
The large G-7 countries are markedly similar in terms of which sectors undertake the R&D. Industry was the leading R&D performer in each; performance shares in the mid-1990s ranged from a little more than 70 percent in the United States and Japan, to somewhat less than 60 percent in Italy. Industry's share ranged between 60 and 70 percent in Germany, France, the United Kingdom, and Canada. (See figure 4-23 and appendix tables 4-45 and 4-46.) The majority of industry's R&D performance was funded by industry itself in each of these countries, followed by government funding. Government's share of funding for industry R&D performance ranged from as little as 2 percent in Japan to about 18 percent in the United States.

In most of the G-7 countries, the academic sector was the next largest R&D performer (at about 15 to 22 percent of the performance total in each country), followed by government laboratories.[46] Only in France was government's R&D performance (which included spending in several nonprivatized

[45]This is not to say that defense-related R&D does not benefit the commercial sector. Unquestionably, technological spillovers have occurred from defense to the civilian sector. But almost as certainly, the benefits are less than if these same resources had been allocated directly to commercial R&D activities. Moreover, considerable anecdotal evidence indicates that technological flow is now more commonly from commercial markets to defense applications, rather than the reverse.

[46]The national totals for Europe, Canada, and Japan include the research component of general university funds (GUF) block grants provided by all levels of government to the academic sector. Therefore, at least conceptually, the totals include both academia's separately budgeted research and research undertaken as part of university departmental R&D activities. In the United States, the Federal Government generally does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. On the other hand, a fair amount of state government funding probably does support departmental research at public universities in the United States. Data on departmental research, considered an integral part of instructional programs, generally are not maintained by universities. U.S. totals may thus be underestimated relative to the R&D effort reported for other countries.

Figure 4-23.
R&D expenditures, by country, performer, and source: Mid-1990s



NOTE: Foreign performers are included in the "industry" and "other domestic" performing sectors.

See appendix tables 4-45 and 4-46.

Science & Engineering Indicators – 1998

industries and in some sizable government laboratories) slightly larger than that of academia. Government's R&D performance share was smallest in Japan and the United States, at about 10 percent of each country's total.

For comparison, 66 percent of the 5.1 trillion rubles spent on R&D in the Russian Federation in 1994 was performed within business enterprises; 28 percent was undertaken in the government sector, including the Russian Academy of Sciences; and most of the remaining 6 percent was performed in institutions of higher education. Notably, however, it is reported that universities are having difficulty competing with Academy institutes in basic research and with industry in applied R&D; therefore, the higher education sector is gradually losing its position in the overall R&D effort (Gohkberg, Peck, and Gacs 1997).

By Source

Consistent with performing most of these countries' R&D activities, the industrial sector provides the greatest proportion of financial support for R&D. Shares for this sector, however, differed somewhat from one country to the next. Industry provided more than 70 percent of R&D funds in Japan, 60 percent in Germany, and about 50 percent in the United States, the United Kingdom, Italy, France, and Canada.[47] In each of these seven countries, government was the second largest source of R&D funding and also provided most of the funds used for academic R&D performance.

The R&D funding share represented by funds from abroad ranged from as little as 0.1 percent in Japan to more than 14 percent in the United Kingdom. Indeed, foreign funding—predominantly from industry for R&D performed by industry—is an important and growing funding source in several countries. Although its growth pattern has seldom been smooth, foreign funding now accounts for more than 10 percent of industry's domestic performance totals in France, Canada, and the United Kingdom. (See figure 4-24.) Such funding takes on even greater importance in many of the smaller OECD and less industrially developed countries (OECD 1997a). In the United States, approximately 11 percent of funds spent on industry R&D performance in 1995 are estimated to have come from majority-owned affiliates of foreign firms investing domestically. This amount was up considerably from the 3 percent funding share provided by foreign firms in 1980.[48] (See appendix table 4-46 and "Foreign R&D in the United States.")

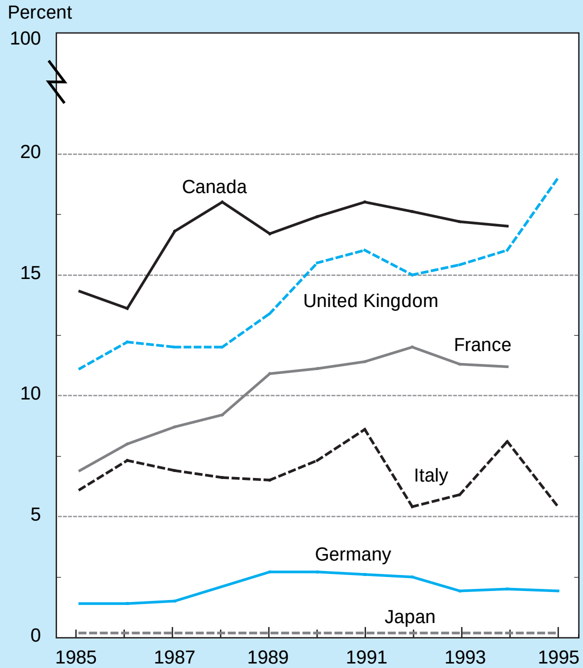
Character of the R&D Effort

The categorization of the R&D effort as either basic research, applied research, or development is quite similar among large, R&D-performing countries for which there are recent data. For several of these countries, however, such

[47]For descriptive statistics on the sectoral composition and size of these OECD countries' industrial R&D activities, see OECD (1997a).

[48]Unlike for other countries, there are no data on foreign sources of U.S. R&D performance. The figures used here to approximate foreign involvement are derived from the estimated percentage of U.S. industrial performance undertaken by majority-owned (i.e., 50 percent or more) nonbank U.S. affiliates of foreign companies. In short, the U.S. foreign R&D totals represent industry funding based on foreign *ownership* regardless of originating source, whereas the foreign totals for the other countries represent *flows* of foreign funds from outside the country to any of its domestic performers.

Figure 4-24.
Share of industry domestic R&D financed from foreign sources



See appendix table 4-49. *Science & Engineering Indicators – 1998*

comprehensive national statistics either are not collected or are considerably out of date. As documented earlier in the chapter, the United States expends about 15 percent of its R&D on activities that performers classify as basic research. (See discussion on basic research in "R&D Support and Performance by Character of Work," earlier in this chapter.) Much of this research is in the life sciences. Basic research accounts for a similar portion of the R&D total in Japan and the Russian Federation—14 percent and 16 percent, respectively. (See figure 4-25.) However, as a share of domestic basic research totals, engineering fields receive relatively more funding in these two countries than in the United States. In France and Germany, the basic research share represented about 21 to 22 percent of the R&D total in the mid-1990s (OECD forthcoming). In each of these countries, development activities accounted for the largest percentage share of total.

International Comparisons of Government R&D Priorities

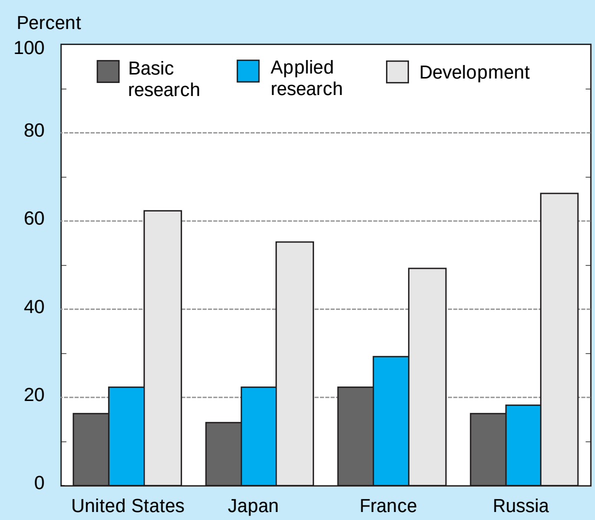
The downturn in R&D growth within OECD countries has been disproportionately caused by negative or near-zero growth in government-funded R&D since the late 1980s. These developments are both a reflection of and an addition to the worldwide R&D landscape changes. Such changes are presenting a variety of new challenges and opportunities. The transition of Eastern European communist systems into market economies, the growth of the S&T base in the Pacific Rim, the increase in the international competitiveness of many countries, public and private sector demands for budgetary accountability, evolution of new and emerging technologies, and realignments within industry and at research universities have combined to present governments with historically unparalleled issues of purpose and direction in designing S&T policy. The following sections highlight government R&D funding priorities in several of the larger R&D-performing nations, summarize broad policy trends, and detail indirect support for research that governments offer their domestic industries through the tax code.

Funding Priorities by National Objective

A breakdown of public expenditures by major socioeconomic objectives provides insight into governmental priorities, which differ considerably across countries.[49] In the United States during 1996, 55 percent of the Government's $69 bil-

[49]Data on the socioeconomic objectives of R&D funding are rarely obtained by special surveys, but rather are generally extracted in some way from national budgets. Since these budgets already have their own methodology and terminology, these R&D funding data are subject to comparability constraints not placed on other types of international R&D data sets. Notably, although each country adheres to the same criteria for distributing their R&D by objective, as outlined in the OECD's Frascati Manual (1994), the actual classification may differ among countries because of differences in the primary objective of the various funding agents. Note also that these data are of government R&D funds only, which account for widely divergent shares and absolute amounts of each country's R&D total.

Figure 4-25.
Distribution of R&D by character of work in selected countries: 1995

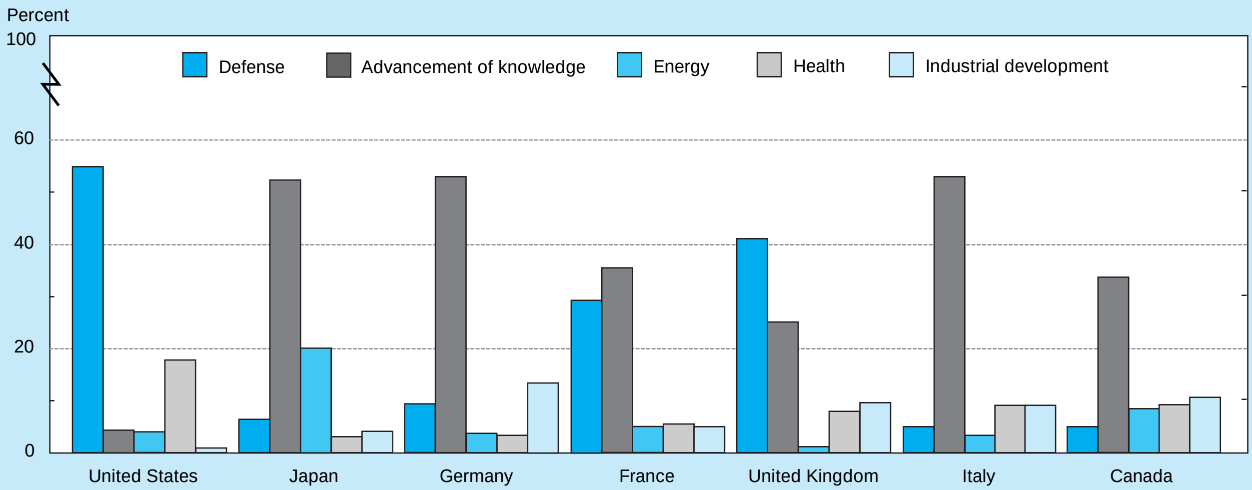


NOTES: France's data are for 1994. The character of work for 8 percent of Japan's R&D is unknown. For Germany, 21 percent of its 1993 R&D was basic research and the rest was undistributed.

SOURCES: Organisation for Economic Co-operation and Development, Main Science and Technology Indicators database (Paris: 1997); and Centre for Science Research and Statistics, *Russian Science and Technology at a Glance:* 1996 (Moscow: 1997).

Science & Engineering Indicators – 1998

Figure 4-26.
Government R&D support, by country and socioeconomic objective: 1995-96



NOTES: Details do not add up to 100 percent because funding for some objectives (e.g., space) is not graphed. R&D is classified according to its primary government objective, although it may support any number of complementary goals. For example, defense R&D with commercial spinoffs is classified as supporting defense, not industrial development. R&D for the advancement of knowledge is not equivalent to basic research.

See appendix table 4-41. *Science & Engineering Indicators – 1998*

lion R&D investment was devoted to national defense; compared with 41 percent in the United Kingdom (of an $8 billion government total); 29 percent in France (of $13 billion); and 10 percent or less each in Germany, Italy, Canada, and Japan. (See figure 4-26 and appendix table 4-41.) These recent figures represent substantial cutbacks in defense R&D in the United States, the United Kingdom, and France, where defense accounted for 63 percent, 44 percent, and 40 percent of government R&D funding, respectively, in 1990. However, defense-related R&D also seems particularly difficult to account for in many countries' national statistics. (See "Accounting for Defense R&D: Discrepancies Between Performer- and Source-Reported Expenditures.")

Different Countries' R&D Emphasis

Advancement of Knowledge. Japanese, German, and Italian government R&D appropriations in 1995-96 were invested relatively heavily (50 percent or more of the $15 billion totals for Japan and Germany, and of the $6 billion total in Italy) in advancement of knowledge—i.e., combined support for advancement of research and general university funds (GUF). Indeed, the GUF component of advancement of knowledge, for which there is no comparable counterpart in the United States, represents the largest part of government R&D expenditure in most of these OECD countries.[50]

Health-Related Research. The emphasis on health-related research is much more pronounced in the United States than in other countries. This emphasis is especially notable in the support of life sciences in academic and similar institutions. In 1996, the U.S. Government devoted 18 percent of its R&D investment to health-related R&D, making such activities second only to defense. (See "Patterns of Federal R&D Support.") Health R&D support approaches 10 percent of total spending in the governmental R&D budgets of the United Kingdom, Italy, and Canada.

Other Areas of R&D Emphasis. In comparison, Japan committed 20 percent of governmental R&D support to energy-related activities, which garnered the second largest share of Japanese R&D, reflecting the country's historical concern with its high dependence on foreign sources of energy. In Canada, 14 percent of the government's $3 billion in R&D funding was directed toward agriculture. Space R&D received

[50]In the United States, advancement of knowledge is a budgetary category for research unrelated to a specific national objective. Furthermore, whereas GUF is reported separately for Japan, Canada, and European countries, the United States does not have an equivalent GUF category: funds to the university sector are distributed to address the objectives of the federal agencies that provide the R&D funds. The treatment of GUF is one of the major areas of difficulty in making international R&D comparisons. In many countries other than the United States, governments support academic research primarily through large block grants that are used at the discretion of each individual higher education institution to cover administrative, teaching, and research costs. Only the R&D component of GUF is included in national R&D statistics, but problems arise in identifying the amount of the R&D component and the objective of the research.

Government GUF support is in addition to support provided in the form of earmarked, directed, or project-specific grants and contracts (funds for which can be assigned to specific socioeconomic categories). In the United States, the Federal Government (although not necessarily state governments) is much more directly involved in choosing which academic research projects are supported than in Europe and elsewhere. Thus, these socioeconomic data are indicative not only of relative international funding priorities, but also of funding mechanisms and philosophies regarding the best methods for financing research. For the 1995-96 period, the GUF portion of total national governmental R&D support was between 38 and 45 percent in Japan, Italy, and Germany; it was between 16 and 20 percent in the United Kingdom, Canada, and France.

Accounting for Defense R&D: Discrepancies Between Performer- and Source-Reported Expenditures

In many OECD member countries, including the United States, there is a considerable difference in the total government R&D support figures reported by government agencies and those reported by performers of the R&D work. Consistent with international guidance and standards (OECD 1994), however, most countries' national R&D expenditure totals and time series are based primarily on data reported by performers. This convention is preferred because performers are in the best position to indicate how much they spent in the actual conduct of R&D in a given year, and to identify the source of their funds. Although there are many reasons not to expect the funding and performing series to match exactly—e.g., different bases used for reporting government obligations (FY) and performance expenditures (calendar year)—the gap between the two R&D series has widened during the past several years in several of the larger OECD member countries. Additionally, the divergence in the series is most pronounced in countries with relatively large defense R&D expenditures.

For 1995 or thereabouts, statistics from OECD's Main Science and Technology Indicators database show that in only 6 of the 28 member countries does defense account for 9 percent or more of government's total R&D budget (because several OECD member countries have never or not recently reported their R&D defense shares, funding differences in those countries could not be evaluated):

- United States (54 percent),
- United Kingdom (41 percent),
- France (30 percent),
- Sweden (21 percent),
- Spain (10 percent), and
- Germany (9 percent).

These six were precisely the countries for which the sums of performer-reported government R&D funding were substantially less than the total government-reported R&D support estimates. As a percentage of government's reported R&D totals that were not accounted for in each country's performer surveys, the largest gaps were reported for:

- Sweden (20.4 percent government R&D "leakage"),
- France (18.4 percent),
- United Kingdom (13.0 percent),
- Spain (9.8 percent),
- United States (8.2 percent—taken from national sources, not OECD databases), and
- Germany (7.5 percent).

For the United States, the funding gap has become particularly acute over the past several years. In the mid-1980s, performer-reported federal R&D exceeded federal reports by $3 to $4 billion annually, or 5 to 10 percent of the government total. This pattern reversed itself so that in 1989 the government-reported R&D total exceeded performer reports by $1 billion. The gap has since grown to about $6 billion; in other words, about 10 percent of the government total in the mid-1990s is unaccounted for in performer surveys. (See figure 4-27 and appendix table 4-47.)

Based on preliminary findings, the difference in federal R&D totals appears to be concentrated primarily in DOD development funding of industry (primarily aircraft and missile firms). For 1995, federal agencies reported $30.5 billion in total R&D obligations *provided* to industrial performers, compared with an estimated $21.2 billion in federal funding *reported* by industrial performers. (DOD reports industry R&D funding of $22.7 billion, while industry reports using $13.9 billion of DOD's R&D funds.) Overall, governmentwide estimates equate to a "loss" of 31 percent of federally reported R&D support. (See figure 4-27 and appendix table 4-47.)

A workshop was held recently at NSF (September 1997) to discuss possible causal factors for the divergence. Although circumstances unique to each country contribute to the discrepancy between the two reporting sources, most participants agreed that the problem resides at least partially in reporting R&D for defense and aerospace programs and in tracking government's international R&D flows. In the case of defense and aerospace programs, workshop participants acknowledged possible differences in agency and performer reporting of "the true R&D content" of large extramural contracts where R&D and production activities are mixed. This circumstance is further complicated by the growing use of industry subcontracting and consortia activities in performing large-scale and complex defense projects. For many European countries, these activities are also collaborative and are performed internationally, so that the final R&D performers may be unable to accurately report the origin of the funds. The Science Resources Studies Division at NSF is conducting further research and investigation into these causal phenomena.

Figure 4-27.
Difference in U.S. performer-reported versus agency-reported federal R&D

NOTE: Difference is defined as the percentage of federally reported federal R&D support.

See appendix table 4-47.

Science & Engineering Indicators – 1998

considerable support in the United States and France (each getting 11 percent of the total), whereas industrial development accounted for 9 percent or more of governmental R&D funding in Germany, the United Kingdom, Italy, and Canada. Industrial development programs accounted for 4 percent of the Japanese total, but just 0.6 percent of U.S. R&D. The latter figure is understated relative to other countries as a result of data compilation differences.

Government R&D Trends in the United States

This section provides greater detail on federal R&D funding priorities in the United States. Such priorities shifted overwhelmingly toward defense programs in the 1980s, which included both DOD programs and nuclear weapons research funded by DOE.[51] Defense R&D spending peaked in 1987 at $47 billion (inflation-adjusted 1992 dollars), when it accounted for 69 percent of the federal R&D total. Since then, the data reflect a distinct de-emphasis on defense priorities, as defense-related R&D dropped to 54 percent of the government total in 1995, where it has since remained. (See figure 4-28 and appendix table 4-39.) Proposed federal R&D funding for defense-related activities accounts for 54 percent of the 1998 total.

Of the federal nondefense functions, health—particularly the R&D programs of HHS—experienced the largest inflation-adjusted R&D funding growth since the early 1980s. Indeed, from 1990 to 1998, health R&D has grown by 26 percent (constant 1992 dollars) while funding for all other nondefense functions grew by just 3 percent. Health programs now account for 18 percent of the federal R&D funding total. In particular, AIDS-related research has grown substantially and now accounts for roughly 12 percent of federal health R&D funds, second only to the 16 percent share directed toward cancer research. Funding for space research, second to health among the nondefense functions in the United States, also grew rapidly in the late 1980s and now accounts for 11 percent of the Federal Government R&D total. Most of the R&D funding growth in this area has been in support of Space Station Freedom and its follow-on International Space Station activities.[52]

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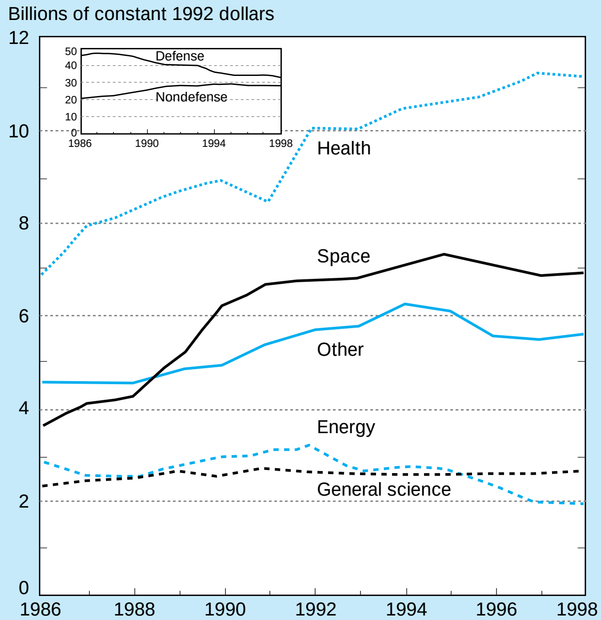
[51]The Office of Management and Budget classifies all activities within the federal budget into 20 functional categories. The budget function classification system provides a means to classify budgetary resources according to the national need being addressed. Fifteen functions contain federal R&D programs. For definitions and details, see NSF (1997c). Data reported here reflect estimates for R&D programs contained in the Administration's 1998 budget proposal submitted to Congress in January 1997 (U.S. OMB 1997). Notably, each specific activity is assigned to only one object code so that programs with multiple objectives will be classified only once under the program's primary functional objective. For example, except for those of the Army Corps of Engineers, all R&D activities sponsored by DOD are classified as defense, even though some activities have secondary objectives such as health, space, or commerce (i.e., defense and commercial dual-use applications). Consequently, these totals are indicative of trends but are not necessarily conclusive. See the recent GAO report for coverage of the Federal Government's total funding by function (U.S. GAO 1997b).

[52]Funding for the Space Station rose from $22 million in 1984, the first year for which this program received a separate budget line item, to $2.1 billion in 1997 (AAAS 1997).

Figure 4-28.
Federal R&D funding, by budget function



NOTE: "Other" includes all nondefense functions not separately graphed, such as agriculture and transportation.

See appendix table 4-39. *Science & Engineering Indicators – 1998*

Among the other major functional recipients of federal R&D funding, general science programs[53] displaced energy activities as the third largest nondefense function in 1996, even though in constant dollars general science research funding is proposed to be no higher in 1998 than it was in 1992. Combined, defense plus these four nondefense functions account for 91 percent of proposed 1998 R&D budget authority.

In terms of *basic* research support, these five functions also account for a 91 percent share of the federal support total, but their relative rankings differ considerably from that for total R&D. (See appendix table 4-40.) Of the proposed $15.3 billion 1998 basic research budget authority, health functions (primarily programs of the National Institutes of Health) account for 46 percent; the general science programs of NSF and DOE for 19 percent; space functions for 10 percent; energy for 9 percent; and defense for 8 percent.

International Comparisons of Government Policy Trends

These aggregate funding priority data only begin to capture the extraordinary changes that have taken place in the international arena over the past several years and the resultant shifts in countries' S&T policy directions. According to a recent OECD (1996) report, a number of common trends among countries are worth highlighting:

- Despite the need to limit public sector expenditures and reduce public sector deficits, support for R&D has remained a priority of public policy throughout OECD member countries. Some countries, such as Japan, have recently announced their intention to increase public sector R&D funding.
- Budgetary restrictions on research funding have led to a growing emphasis on ensuring the efficient use of resources through more extensive program and policy evaluation.
- Many countries are focusing R&D support on specific technologies such as information technologies, energy and environmental technologies, biotechnology, and advanced materials.
- To foster international competitiveness, governments have maintained and expanded measures to strengthen the links between science and industry by establishing initiatives that increase collaboration between higher education and business sectors and between government agencies and industry.
- Many OECD countries have determined that fiscal measures to support industrial R&D represent an important component of public policy aimed at increasing overall R&D and stimulating industrial innovation.

International R&D Tax Treatment

Tax treatment of R&D in OECD countries is broadly similar, with some variations in the use of R&D tax credits (OECD 1996a). The following are main features of the R&D tax instruments:

- Practically all countries (including the United States) allow industry R&D expenditures to be *100 percent deducted* from taxable income in the year they are incurred.
- In most countries, R&D expenditures can by *carried forward* or deducted for some 3 to 10 years. (In the United States, there is a 3-year carry-forward on R&D expenditures and a 15-year carry-forward on R&D capital assets).
- About half the countries (including the United States—see below) provide some type of additional R&D *tax credit* or incentive, with a trend toward using incremental credits and more targeted approaches such as those favoring basic research.
- Several countries have special provisions that favor R&D in small and medium-size enterprises. (In the United States, special credit provisions exist for small startup firms, but more direct federal R&D support is provided through grants to small firms. See "SBIR Program Expands Support for Small Business R&D.")
- There are a growing number of R&D tax incentives being offered at the subnational (provincial and state) levels, including in the United States (see below).

[53]Research activities classified under this "general science" budget category are seen as contributing more broadly to the nation's science and engineering base than do basic research programs that support agency missions.

SBIR Program Expands Support for Small Business R&D

The Small Business Innovation Research (SBIR) Program was created in 1982 to strengthen the role of small firms in federally supported R&D. Since that time, the SBIR Program has directed nearly 37,000 awards worth more than $5.5 billion in R&D support to thousands of qualified small high-tech companies on a competitive basis. Under this program, which is coordinated by the Small Business Administration (SBA) and is in effect until the year 2000, when an agency's external R&D obligations (those exclusive of in-house R&D performance) exceed $100 million, the agency must set aside a fixed percentage of such obligations for SBIR projects. This percentage initially was set at 1.25 percent, but under the Small Business Research and Development Enhancement Act of 1992, it rose incrementally to 2.5 percent in 1997.

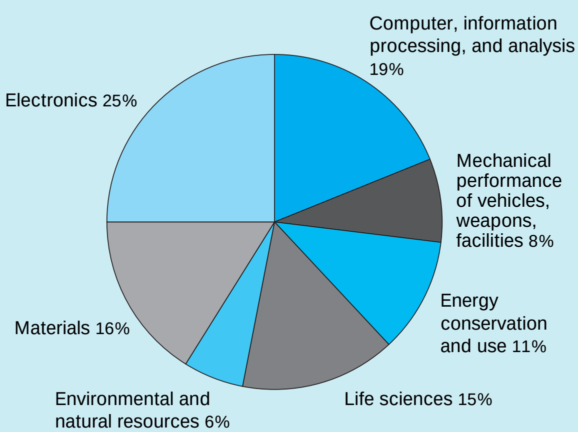
To obtain funding, a company applies for a Phase I SBIR grant. The proposed project must meet an agency's research needs and have commercial potential. If approved, grants of up to $100,000 are made to allow the scientific and technical merit and feasibility of an idea to be evaluated. If the concept shows potential, the company can receive a Phase II grant of up to $750,000 to develop the idea further. In Phase III, the innovation must be brought to market with private sector investment and support. No SBIR funds may be used for Phase III activities.

Eleven federal agencies participated in the SBIR Program in 1995, making awards totaling $865 million—an amount equivalent to 1.3 percent of all government R&D obligations. The total amount obligated for SBIR awards in 1995 was 30 percent more than in 1994, a result of legislatively required increases in R&D amounts agencies must earmark for SBIR. Whereas 71 percent of the *grants* awarded were Phase I grants (3,085 of 4,348 awards in 1995), roughly 70 percent of total SBIR *funds* were disbursed through Phase II grants. Approximately 48 percent of all SBIR obligations were provided by DOD, mirroring this agency's share of the federal R&D extramural funding total. (See appendix table 4-37.)

There have not been many assessments of the overall effectiveness of the SBIR Program, although it is generally agreed that the quality of funded research proposals is high. For example, GAO (1997c) reports that about one-half of surveyed DOD SBIR awards have led to sales of a product, process, or service; about 52 percent of these sales have been made to DOD or to its prime contractors, with remaining sales to private sector customers or others.

SBA classifies SBIR awards into various technology areas. In terms of all SBIR awards made during the 1983-95 period, the technology area receiving the largest (value) share of Phase I awards was advanced materials. Electronics device performance and computer communications systems were the leading technology areas for Phase II awards. More broadly, roughly one-fifth of all awards made from 1983 to 1995 were computer-related and one-fourth involved electronics. (See figure 4-29.) Each received more than 70 percent of its support from DOD and NASA. One-sixth of SBIR awards went to life sciences research, with the bulk of this funding provided by HHS.

Figure 4-29.
Small Business Innovation Research awards, by technology area: 1983-95



SOURCE: U.S. Small Business Administration, *Small Business Innovation Development Act* (Washington, DC: 1997).

Science & Engineering Indicators – 1998

U.S. Federal and State R&D Tax Credits

Credits Provided by the Federal Government. As have many other countries, the U.S. Government has tried policy instruments in addition to direct financial R&D support to indirectly stimulate corporate research spending. The most notable of these efforts has been to offer tax credits on incremental research and experimentation (R&E) expenditures.[54] The credit was first put in place in 1981 and has been renewed eight times, most recently through the end of May 1998.[55] Although the computations are complicated, the tax code provides for a 20 percent credit for a company's qualified

[54]Not all R&D is eligible for such credit, which is limited to expenditures on laboratory or experimental R&D.

[55]In its latest extension, the credit was renewed in August 1997 retroactive to June 1997. The credit had lapsed from mid-1995 to mid-1996 before being restored in 1996 to a modified form. See also Poterba (1997) for a discussion of international elements of corporate R&D tax policies.

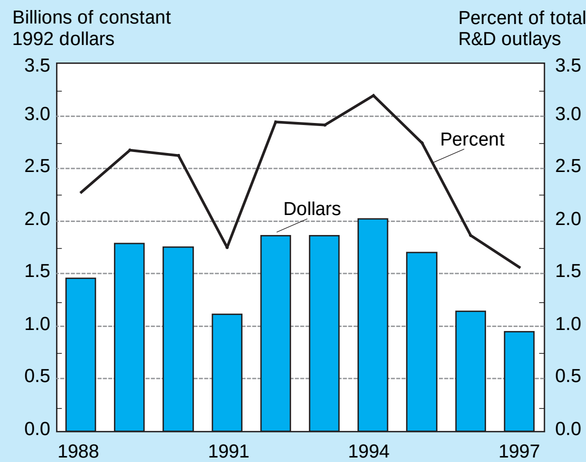
R&D amount that exceeds a certain threshold.[56] Since 1986, companies have been allowed to claim a similar credit for basic research grants to universities and other qualifying nonprofit institutions, although the otherwise deductible R&E expenditures are reduced by the amount of the basic research credit. This basic research provision generally has gone unutilized.[57]

The dollar value of R&E tax credits actually received by firms is unknown. Not all of the tax credits initially claimed by firms are allowed. Indeed, data from the Internal Revenue Service indicate that in any given tax year, this dollar value can be 20 to 30 percent less than the amount for which firms file claims—nearly $1.6 billion in 1992, the most recent year for which data are available (U.S. OTA 1995). This amount has fluctuated since the credit's inception in 1981, but has remained rather steady since 1988. (See appendix table 4-38.)

Additionally, as part of the federal budget process, Treasury annually calculates estimates of foregone tax revenue (tax expenditures) resulting from preferential tax provisions, including the R&E tax credit. As one measure of budgetary effect, Treasury provides outlay-equivalent figures that allow a comparison of the cost of this tax expenditure with the cost of a direct federal R&D outlay. Between 1981 and 1996, more than $27 billion was provided to industry through this indirect means—an amount equivalent to about 3 percent of direct federal R&D support. (See figure 4-30 and appendix table 4-38.)

Effectiveness of Credits Uncertain. Results of various studies undertaken since the mid-1980s have given the tax credit mixed reviews for its overall effectiveness. Assessments undertaken soon after initial enactment of the credit (those using data for the years 1981 to 1983) concluded that the R&E tax credit cost more in lost revenues than it produced in additional R&E expenditures. More recent and somewhat more comprehensive studies (using data for the years 1988 and later) indicate that the amount of induced R&E spending approximates revenue cost in the short term and exceeds it in the long term (U.S. OTA 1995 and U.S. GAO 1996c).[58] Although some firms rely heavily on the credit—e.g., industries with rapidly expanding R&D outlays (as in communications and information technology) and industries for which R&D performance strongly affects market valuation (as in biotechnology)—preliminary evidence indicates that the R&E tax credit rarely factors into individual firms' R&D planning processes. There are no studies that have empirically investigated the credit's net benefit to society.

Figure 4-30.
R&E tax credits: Total and percentage of government R&D outlays



NOTE: Bar charts represent outlay equivalents of research and experimentation (R&E) tax credits.

See appendix table 4-38. *Science & Engineering Indicators – 1998*

Credits Provided by State Governments. The Federal Government is not the only source of fiscal incentives for increasing research. According to a recent survey of the State Science and Technology Institute (1997), 35 states offered some type of incentive for R&D activity in 1996. Many states offered an income tax credit modeled after the federal R&E credit guidelines. Fifteen states applied the federal research tax credit concepts of qualified expenditures or base years to their own incentive programs, although they frequently specified that the credit could only be applied to expenditures for activities taking place within the state. Other types of R&D incentives included sales and use tax credits and property tax credits.

Internationalization of R&D and Technology

Globalization of R&D activities has expanded considerably during the past two decades. This growth is exhibited in each of the R&D-performing sectors. Gains in cross-country academic research collaboration are indicated by the substantial increase in international coauthorships. (See chapter 5, "Trends in International Article Production.") In the public sector, the rapid rise in international cooperation has spawned activities that now account for up to 10 percent of government R&D expenditures in some countries. International collaboration in scientific research involving extremely large "megascience" projects also has grown, reflecting scientific and budgetary realities. Excellent science is not the domain of any single country, and many scientific problems involve

[56]The complex base structure for calculating qualified R&D spending was put in place by the Omnibus Reconciliation Act of 1989. With various exceptions, a company's qualifying threshold is the product of a fixed-base percentage multiplied by the average amount of the company's gross receipts for the four preceding years. The fixed-base percentage is the ratio of R&E expenses to gross receipts for the increasingly distant 1984-88 period. Special provisions cover startup firms.

[57]In 1992, firms applying for the R&E credit spent about $1 billion on research performed by educational and scientific organizations, of which—after various qualification restrictions—the basic research credit contributed less than $200 million toward the R&E tax credit (U.S. OTA 1995).

[58]Whatever its ultimate impact on R&D spending, the tax credit has certainly influenced spending less than it could have, were it less subject to erratic legislative treatment. The tax credit has had to be repeatedly (almost annually) renewed, its calculation provisions have changed considerably over the years, and it was even allowed to lapse several times—circumstances that created considerable uncertainty for businesses that otherwise would have planned to take the credit.

major instrumentation and facility costs that appear much more affordable when cost-sharing arrangements are in place. Additionally, some scientific problems, such as global change research, demand an international effort.

In the private sector, international R&D collaboration is also on the rise, as is indicated by the growth of formal cooperative partnerships between firms. Growing international linkages are evidenced as well by the rise of overseas R&D activities performed under contract and through subsidiaries, and by the establishment of independent research facilities. Although the reasons for this growth are complex, multilateral industrial R&D efforts appear to be a response to the same competitive factors affecting all industries: rising R&D costs and risks in product development, shortened product life cycles, increasing multidisciplinary complexity of technologies, and intense foreign competition in domestic and global markets.

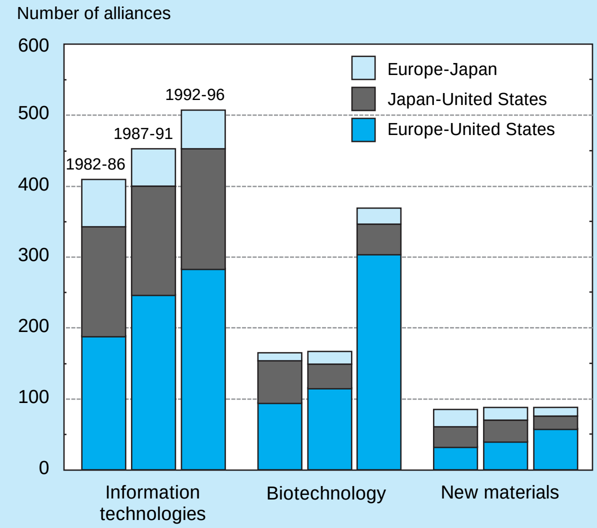
International Strategic Technology Alliances

Industrial firms increasingly have sought global research partnerships as a means of strengthening their core competencies and expanding into technology fields considered critical for maintaining market share. Such international strategic technology alliances increased sharply throughout the industrialized world in the early 1980s and accelerated as the decade continued.[59] Although growth of newly established alliances tapered off in the early 1990s, there is evidence of further expansion during the middle part of this decade. Formation of these strategic technology partnerships has been particularly extensive among high-tech firms in such core areas as information technologies, biotechnology, and new materials. (See figure 4-31 and appendix table 4-48.) Technological complementarity and reduction of the innovation period are primary catalysts for entering into core technology alliances; market entry and production-related factors are more relevant in technologically less advanced or more mature markets.

[59]Information in this section is drawn from an extensive database compiled in the Netherlands (MERIT-CATI—Maastricht Economic Research Institute on Innovation and Technology's Cooperative Agreements and Technology Indicators database) on more than 10,000 inter-firm cooperative agreements involving thousands of different parent companies. In the CATI database, only agreements that contain arrangements for transferring technology or joint research are collected. The data summarized here extend by three years the information for 1970 to 1993 presented in Hagedoorn (1996). These counts are restricted to strategic technology alliances, such as joint ventures for which R&D or technology sharing is a major objective, research corporations, joint R&D pacts, and minority holdings coupled with research contracts.

CATI is a literature-based database; its key sources are newspapers, journal articles, books, and specialized journals that report on business events. CATI's main drawbacks and limitations are that (1) data are limited to activities publicized by the firm, (2) agreements involving small firms and certain technology fields are likely to be underrepresented, (3) reports in the popular press are likely to be incomplete, and (4) it probably reflects a bias because it draws primarily from English-language materials. CATI information should therefore be viewed as indicative and not comprehensive.

Figure 4-31.
New international strategic technology alliances, by technology and world region



See appendix table 4-48. *Science & Engineering Indicators – 1998*

Nature of Cooperative Activity Changing

As the numbers have increased, the forms of cooperative activity have changed as well. The most prevalent modes of global industrial R&D cooperation in the 1970s were joint ventures and research corporations. In these arrangements, at least two companies share equity investments to form a separate and distinct company; profits and losses are shared according to the equity investment.[60] In the second half of the 1980s and continuing into the 1990s, joint nonequity R&D agreements became the most important form of partnership. Under such agreements, two or more companies organize joint R&D activities to reduce costs and minimize risk, while pursuing similar innovations. Participants share technologies but have no joint equity linkages (Hagedoorn 1990 and 1996).

Growth in Core Technology Alliances

During the first half of the 1970s, strategic alliances were almost nonexistent in core technologies, as well as in other sectors, but expanded rapidly late in the decade. The number of newly made partnerships in the three core technologies—information technologies, biotechnology, and new materials—rose from about 10 alliances created in 1970 to about 140 in 1980 (Hagedoorn 1996). By 1986, this number had risen to 400 alliances, 250 of which were intraregional (that is, made between firms located in the same broad regions of Europe, Japan, or the United States); 150 were interregional (between firms located in separate regions). The majority of both types of alliances was between

[60]Joint ventures are companies that have shared R&D as a specific company objective, in addition to production, marketing, and sales. Research corporations are joint R&D ventures with distinctive research programs.

firms sharing information technologies such as computer software and hardware, telecommunications, industrial automation, and microelectronics.

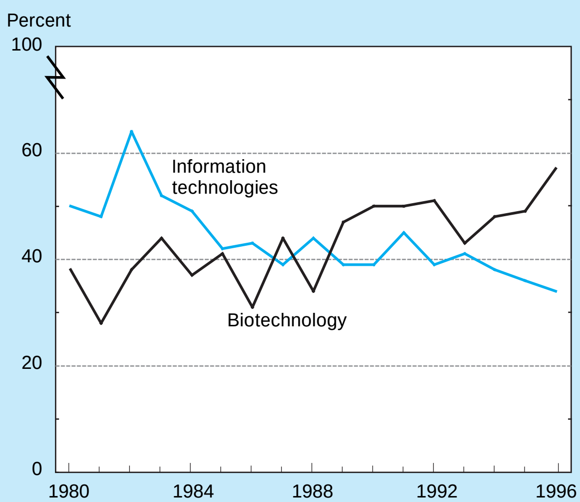
For the decade since 1986, growth in core technology alliances has been continuous though irregular. Of the roughly 2,500 information technology alliances formed during this period, the largest number has been among U.S. companies and between European and U.S. firms. Among the 1,100 strategic biotechnology alliances, U.S.-European interregional partnerships have been more prevalent than any other, especially during the mid-1990s. In fact, by 1996 almost 60 percent of all biotechnology collaborations were interregional. The opposite was true of partnerships focusing on information technology, for whom intraregional alliances were created twice as often as interregional partnerships in 1996. (See figure 4-32.)

U.S. Industry's International R&D Investment Balance

Stiff international competition in research-intensive, high-technology products, along with market opportunities, have compelled firms throughout the world to expand their overseas research activities. Foreign sources account for a growing share of domestic R&D investment totals in many countries (see figure 4-24), and many firms have R&D sites in countries outside of their home base. (See "U.S. Research Facilities of Foreign Firms" for a summary of recent statistics on foreign R&D sites in the United States.) Firms tend to adopt a global approach to R&D for one of two basic reasons:

1. Multinational firms seek a foreign R&D presence to support their overseas manufacturing facilities or to adapt standard products to the demand there. This arrangement constitutes a *home-base exploiting* site, where information tends to flow to the foreign laboratory from the central home laboratory.
2. The foreign site is established to tap knowledge from competitors and universities around the globe, constituting a *home-base augmenting* site, where information tends to flow from the foreign laboratory to the central home laboratory.

Figure 4-32.
Interregional alliances as a share of world total strategic alliances, by technology



NOTE: Interregional alliances include those between the United States and Europe, the United States and Japan, and Europe and Japan.

See appendix table 4-48. *Science & Engineering Indicators – 1998*

According to a recent study of 238 foreign R&D sites, 45 percent of the labs were home-base augmenting and 55 percent were home-base exploiting (Kuemmerle 1997).[61]

U.S.-Foreign Industrial R&D Flows

U.S. companies' R&D investment abroad is *roughly* equivalent to R&D expenditures in the United States by majority-owned U.S. affiliates of foreign companies.[62] In 1994 (the latest year for which complete data from the Bureau of Economic Analysis—BEA—are available), industrial R&D flows into the United States totaled $12.7 billion, compared with the $11.5 billion in R&D expenditures by U.S. multinational firms in other countries. (See figure 4-33.) This approximate balance in R&D investment flows has persisted since 1989 when the majority-owned data first became available on an annual basis. However, a general shift has occurred in the aggregate "balance" of R&D flows over this period. In the early 1990s, a greater proportion of international R&D was spent abroad than was invested in the United States. It now appears the reverse is true, and more industrial R&D money is flowing into the United States than U.S. firms are investing abroad.

Europe is both the primary source and the main destination of these U.S.-foreign industrial R&D flows. (See figure 4-34.) European firms invested $11.6 billion of R&D money in the United States in 1995; the Asian (including the Middle East) and Pacific region provided the second largest source of foreign R&D funds, with $1.6 billion. Similarly, U.S. companies invested $8.3 billion of R&D in Europe and $1.9 billion in Asian and Pacific region investments. Bilateral R&D

[61]The terms "home-base exploiting" and "home-base augmenting" are taken directly from Kuemmerle (1997). However, others (notably Mowery 1997) have made similar observations on the reasons for the expanding global R&D arrangements. Furthermore, Mowery notes that the use of international R&D strategies to establish networks for the creation and strengthening of firm-specific technological capabilities (that is, home-base augmenting) is likely to become more important than market exploitation-driven activities in the future.

[62]These overseas R&D data are from the U.S. Bureau of Economic Analysis (BEA) survey on U.S. Direct Investment Abroad. The definition used by BEA for R&D expenditures is from the Financial Accounting Standards Board Statement No. 2; these expenditures include all charges for R&D performed for the benefit of the affiliate by the affiliate itself and by others on contract. BEA detail is available for 1982 and annually since 1989. Data on foreign sources of industrial R&D performed in the United States come from an annual survey of Foreign Direct Investment in the United States, also conducted by BEA. BEA reports that foreign R&D totals are comparable with U.S. R&D business data published by NSF. Industry-specific comparisons, however, are limited because of differences in the industry classifications used by the two surveys (Quijano 1990).

U.S. Research Facilities of Foreign Firms

Consistent with the worldwide trend of multinational firms establishing an R&D presence in multiple countries, considerable growth has occurred in R&D facilities being operated by foreign companies in the United States. According to a 1992 survey of 255 foreign-owned free-standing R&D facilities in the United States, about half were established during the previous six years (Dalton and Serapio 1993). These counts are only for those R&D facilities that are 50 percent or more owned by a foreign parent company.* In a recent update to this study (Dalton and Serapio 1998), the authors characterize the activities of 676 U.S. R&D facilities run by more than 350 European, Japanese, and other foreign companies. Significant findings of this study follow:

- R&D facilities owned by Japanese firms continue to far outnumber those of all other countries. Japanese companies owned 244 R&D facilities in the United States in 1996, British companies owned 102, German companies owned 93, and French and Swiss companies each owned more than 40. (See text table 4-10.) South Korean companies have a rapidly growing presence in the United States, owning 32 R&D facilities here in 1996—6 more than had been identified in 1994, and about 20 more than listed for 1992.
- The activities of these foreign facilities were highly concentrated in several industries: drugs and biotechnology (111 facilities), chemicals and rubber (110), computers and computer software (88), food and consumer goods (61), high-definition television and other electronics (59), instruments and medical devices (52), and automotive products (50). Japanese companies account for most of the R&D centers in the electronics and automotive industries, while European companies have far more R&D sites focusing on pharmaceuticals and chemicals.
- Foreign R&D facilities were heavily concentrated in selected areas of the country, notably California's Silicon Valley and greater Los Angeles, Detroit, Boston, Princeton, and North Carolina's Research Triangle Park.

The most important reasons cited for Japanese foreign electronics R&D investment in the United States were to acquire technology and to keep abreast of technological developments (a home-base augmenting strategy). For automotive R&D, investment motives centered on assisting the parent company in meeting U.S. environmental regulations and customer needs (a home-base exploiting strategy).

*An R&D facility typically operates under its own budget and is located in a free-standing structure outside of and separate from the parent's other U.S. facilities (e.g., sales and manufacturing). This definition of an R&D facility consequently excludes R&D departments or sections within U.S. affiliates of foreign-owned companies.

Text table 4-10.
U.S. R&D facilities of foreign companies, by selected industry and country: 1996

Industry	Total	Japan	United Kingdom	Germany	France	Switzerland	South Korea	Netherlands	Canada	Other
Total	676	244	102	93	44	42	32	30	20	69
Computers	39	22	1	2	0	0	7	2	5	0
Software	49	34	8	2	0	0	1	1	2	1
Semiconductors	32	18	0	2	0	0	10	2	0	0
Telecommunications	35	17	3	4	2	1	0	1	7	0
Opto-electronics	19	9	3	2	0	0	0	0	0	5
HDTV, other electronics	59	32	9	7	3	1	5	1	1	0
Drugs, biotechnology	111	26	15	24	6	19	2	5	0	14
Chemicals, rubber	110	23	18	27	14	7	1	6	4	10
Metals	23	8	5	2	0	1	0	2	2	3
Automotive	50	31	1	8	2	0	4	2	0	2
Machinery	27	5	6	3	4	2	0	0	1	6
Instrumentation, medical devices	52	6	20	6	3	6	0	3	2	6
Food, consumer goods	61	11	11	4	1	9	1	9	4	11

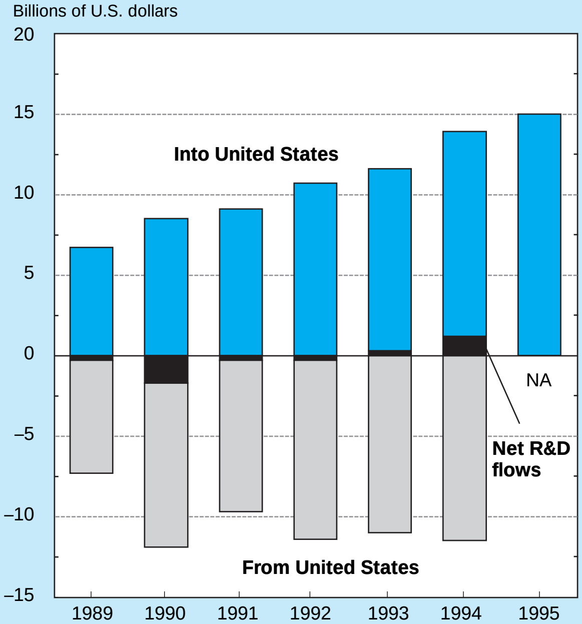
HDTV = high-definition television

NOTE: Sum of industry details may not add up to country totals because of cross-industry R&D at facilities.

SOURCE: D.H. Dalton and M.G. Serapio, Jr., *Globalizing Industrial Research and Development* (Washington, DC: U.S. Department of Commerce, Technology Administration, 1998).

Science & Engineering Indicators - 1998

Figure 4-33.
Balance in U.S. and foreign industrial R&D investment flows



NA = not available

See appendix tables 4-51 and 4-53.

Science & Engineering Indicators – 1998

investments between Canada and the United States are in the $1 billion to $1.4 billion range. R&D flows remain small to negligible both into and out of Latin America and Africa.

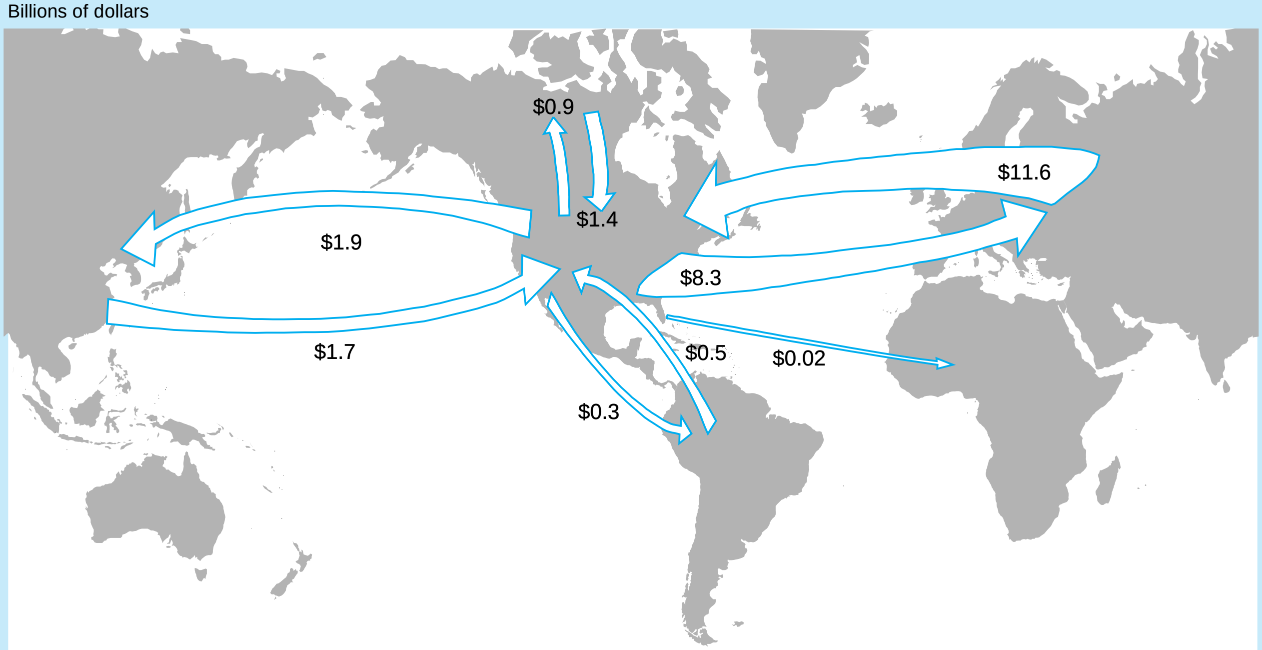
U.S. Industry's Overseas R&D

Since 1985, U.S. firms generally increased their annual funding of R&D performed outside the country. (See appendix table 4-50.) Indeed, from 1985 to 1995, U.S. firms' investment in overseas R&D increased three times faster than did company-funded R&D performed domestically (10.1 versus 3.4 percent average annual constant-dollar growth). Industries' total R&D performance, including funding from federal sources, grew at a meager 1.4 percent annual rate over the 1985-95 period. Equivalent to about 6 percent of industry's domestic R&D funding in 1985, overseas R&D now accounts for 12 percent of U.S. industry's on-shore R&D expenditures.[63] (See figure 4-35.) Additionally, according to BEA data, the majority-owned (that is, 50 percent or more) foreign-affiliate share of U.S. multinational companies' worldwide R&D expenditures increased from 9 percent in 1982 to 13 percent in 1990, where it remained through 1994 (Mataloni and Fahim-Nader 1996).

[63]These overseas R&D shares are taken from the NSF industrial R&D data series, not the BEA Direct Investment Abroad series used in the "International R&D Investment Balance" discussion. However, BEA data on the country destination of the U.S. overseas R&D investment are more complete than the NSF series and therefore are used to describe country patterns. NSF reports 1994 and 1995 overseas R&D totals of $9.4 billion and $13.1 billion, respectively; BEA estimates 1994 overseas R&D expenditures by U.S. companies and their foreign affiliates at $11.5 billion.

Figure 4-34.
U.S. flows of industrial R&D, by world region

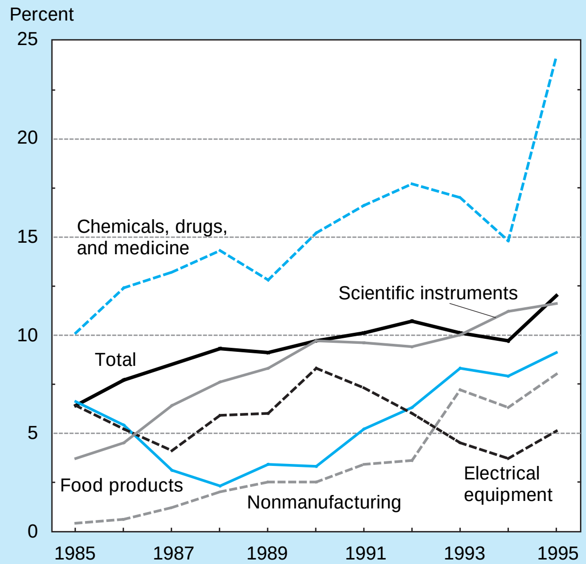
Billions of dollars



NOTE: R&D flows from the United States are for 1994 and R&D flows into the United States are for 1995.

See appendix tables 4-51 and 4-53.

Figure 4-35.
Ratio of U.S. overseas R&D to company-financed domestic R&D, by industry



See appendix table 4-50. *Science & Engineering Indicators – 1998*

Lion's Share for Chemicals Industry. R&D investment by U.S. companies and their foreign subsidiaries in the chemicals (including pharmaceuticals and industrial chemicals) industry accounts for the largest share and greatest growth of foreign-based R&D activity. Indeed, drug companies accounted for 20 percent of total 1995 overseas R&D ($2.6 billion of the $13.1 billion total)—equivalent to 25 percent of the pharmaceutical industry's domestically financed R&D. (See appendix table 4-50.) Of other major R&D-performing manufacturers, recent trends show the overseas R&D investment share of total R&D financing rising considerably for scientific instruments and the food industry.

Increased R&D Activity in Nonmanufacturing Industries. Similarly, the combined total for all nonmanufacturing industries shows substantial increases in foreign R&D activity since 1985, rising from 0.4 percent of domestic R&D funding that year to 8.0 percent in 1995. Part of this growth reflects increased international R&D financing by firms historically classified as nonmanufacturing industries (particularly computer, data processing, and architectural services). Part of the increase reflects the movement of firms previously classified as manufacturers (e.g., office computing companies) to service sector industries (e.g., software development).

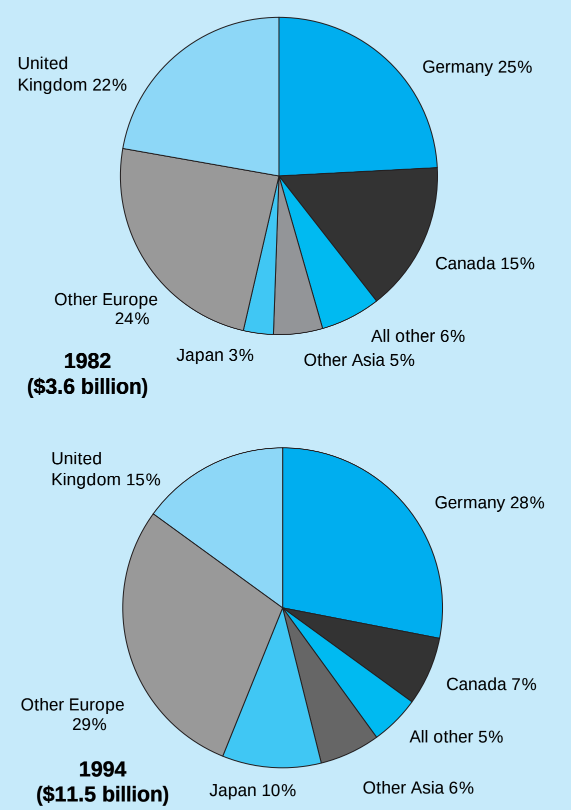
Most R&D Performed in Europe, Though Shifting East. As indicated by BEA data on majority-owned foreign affiliates of nonbank U.S. multinational companies, most of the U.S. 1994 overseas R&D was performed in Europe—primarily Germany (28 percent of the U.S. overseas total), the United Kingdom (15 percent), France (11 percent), and Ireland (4 percent). (See figure 4-36 and appendix table 4-51.) Collectively, however, the current 72 percent European share of the U.S. total R&D investment abroad is somewhat less than the 78 percent share reported as recently as 1990. Since the early 1980s, U.S. R&D investments abroad have generally shifted away from the larger European countries and Canada, and toward Japan and other Asian countries.

By affiliate industry classification, more than one-half of the 1994 German-based R&D was performed by transportation equipment companies. In the United Kingdom and France, the chemicals industry accounted for the largest share of each countries' respective totals, whereas in Ireland, the machinery industry performed most of this U.S.-funded R&D. In Japan, which accounted for 10 percent of U.S. companies' 1994 R&D performed abroad, the largest share was performed in chemicals firms' foreign affiliates. (See text table 4-11.) Notably, the U.S. R&D investment in Asian countries other than Japan has grown substantially; for example, U.S. R&D spending in Singapore (primarily in machinery industries) now surpasses that in many European nations.

Foreign R&D in the United States

Like U.S. firms' overseas R&D funding trends, R&D activity by foreign-owned companies in the United States has increased significantly since the mid-1980s. From 1987 to 1995, inflation-adjusted R&D growth from foreign firms (U.S.

Figure 4-36.
U.S. R&D performed abroad



See appendix table 4-51. *Science & Engineering Indicators – 1998*

Text table 4-11.
R&D performed overseas by majority-owned foreign affiliates of U.S. parent companies, by selected region/country and industry of affiliate: 1994
(Millions of dollars)

Region/country	All industries	Manufacturing: Total	Chemicals	Machinery	Electrical equipment	Transportation equipment	Nonmanu-facturing
Total	12,097	10,147	3,119	2,034	797	2,812	1,950
Canada	861	D	226	34	D	272	D
Europe	8,791	D	2,204	1,600	D	2,309	D
Belgium	516	373	344	3	2	4	143
France	1,357	1,142	543	202	D	D	215
Germany	2,808	2,630	296	530	128	1,435	178
Ireland	462	435	87	292	43	0	27
Italy	409	382	189	93	26	30	27
Netherlands	418	345	63	12	163	5	73
Switzerland	191	D	10	8	D	0	D
United Kingdom	2,179	1,938	616	433	D	D	241
Rest of Europe	451	D	56	27	D	D	D
Asia and Pacific	1,856	1,381	D	381	D	68	475
Australia	230	D	40	D	1	D	D
Japan	1,123	787	397	77	136	6	336
Singapore	238	225	2	195	27	0	13
Taiwan	110	D	D	D	D	D	D
Western Hemisphere	481	465	197	14	22	164	16
Brazil	239	235	50	5	14	D	4
Mexico	185	182	115	9	7	D	3
Middle East	94	D	D	5	D	0	D
Africa	15	14	10	1	*	*	1

* = less than $500,000; D = withheld to avoid disclosing operations of individual companies

NOTES: Includes direct investments of majority-owned nonbank foreign affiliates of U.S. parents. Includes R&D expenditures conducted by the foreign affiliates for themselves or for others under a contract. Bureau of Economic Analysis expenditures differ from National Science Foundation-reported expenditures in appendix table 4-50.

SOURCE: U.S. Bureau of Economic Analysis, *U.S Direct Investment Abroad: Operations of U.S. Parent Companies and Their Foreign Affiliates* (Washington, DC: U.S. Government Printing Office, 1997).

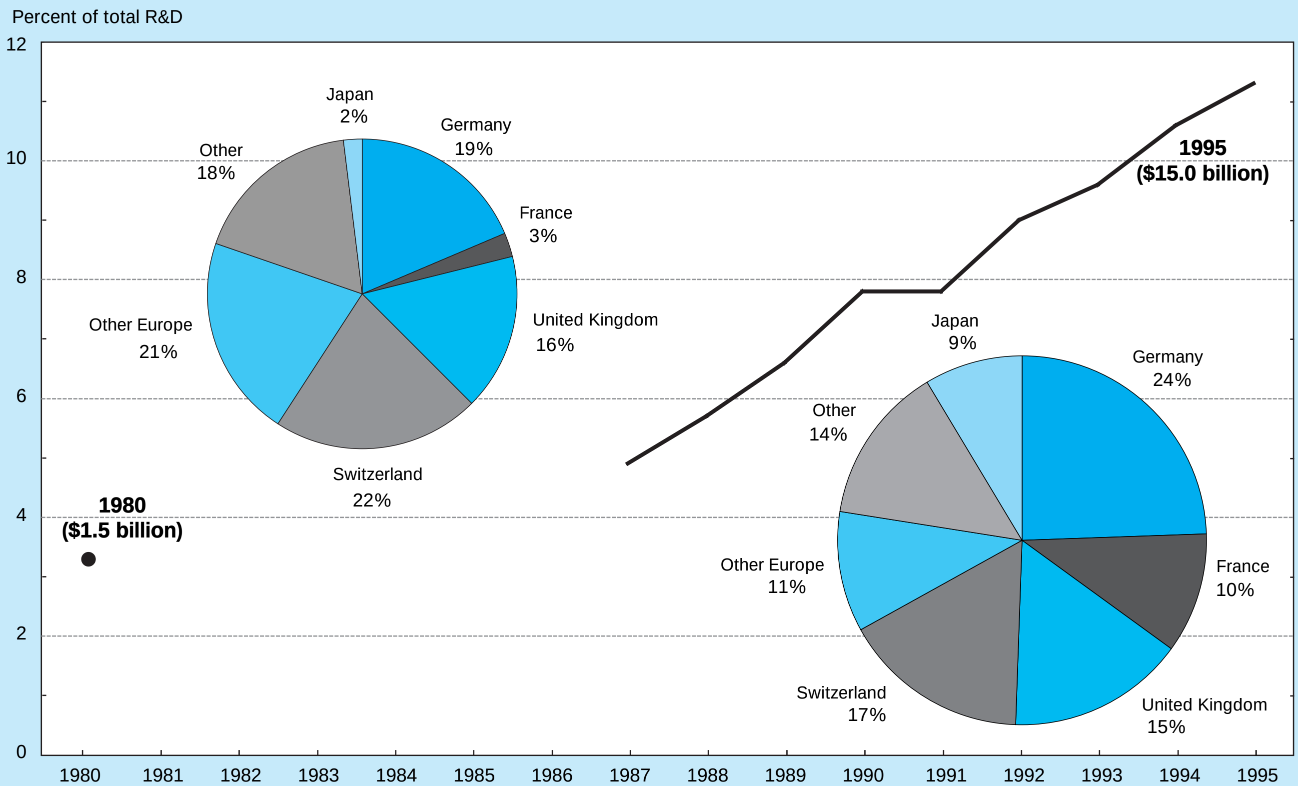
Science & Engineering Indicators - 1998

affiliates with a foreign parent that owns 50 percent or more of the voting equity) averaged 12.5 percent per year.[64] This growth contrasts quite favorably with the implied 3 percent average annual rate of real increase in U.S. firms' domestic R&D funding, and is almost 10 times the 1.3 percent 1987-95 growth rate of total domestic industrial R&D performance (including activities funded by foreign firms and the Federal Government). As a result of these various funding trends, foreign R&D was equivalent to 11 percent ($15 billion) of total industrial R&D performance in the United States in 1995—or more than double that of its equivalent 5 percent share in 1987. Majority-owned affiliates accounted for just a 3 percent share of the U.S. 1980 industrial performance total. (See figure 4-37.)

Most R&D Flows From Five Countries. The geographic pattern of R&D flows into the United States differs from the trends noted for U.S. R&D spending abroad. Whereas countries other than G-7 countries have become increasingly important as a destination for U.S. funding, they are less important in terms of foreign R&D investments here. In 1995, 75 percent of foreign funding came from just five countries—Germany, Switzerland, the United Kingdom, France, and Japan. In 1980, firms from these five countries accounted for 62 percent of foreign R&D flows into the United States. Although the R&D flows from Canada and other European countries also increased steadily over the past 15 years, at least part of the significant expansion of foreign R&D ex-

[64]Although BEA considers all of an investment (including R&D) to be foreign if 10 percent or more of the investing U.S.-incorporated firm is foreign-owned, special tabulations were prepared by BEA to reveal R&D expenditures in the United States of those firms in which there is majority foreign ownership of 50 percent or more. For 1995, the 10 percent foreign ownership threshold results in an estimated $17.7 billion foreign R&D investment total. (See appendix table 4-52.) R&D expenditures of majority-owned U.S. affiliates of foreign companies were $15 billion. (See appendix table 4-53.) Tabulations for the majority-owned firms' R&D financing are used for most of the analyses provided here; the sole exception is the use of foreign R&D data at the 10 percent threshold for review of country-specific funding patterns for individual industrial sectors. (See text table 4-12.) Such data for majority-owned affiliates are not available.

Figure 4-37.
U.S. industrial R&D financed by majority-owned foreign firms: Share of total and sources of funds



NOTE: Data are not available for 1981-86.

See appendix table 4-53.

Science & Engineering Indicators – 1998

penditures is attributable to several major acquisitions by foreign multinational companies of U.S. firms, particularly of U.S. pharmaceutical and biotechnology firms with large R&D budgets.

Research Concentrated in Three Industries. Foreign-funded research was concentrated in three industries in 1995—drugs and medicines (mostly from Swiss and British firms), industrial chemicals (funded predominantly by German firms), and electrical equipment (one-third of which came from French affiliates).[65] These three industries accounted for three-fifths of the $17.7 billion total 1995 foreign R&D investment by affiliates in which there was at least 10 percent foreign ownership. Concurrent with gains reported for all domestic U.S. R&D performance, foreign—particularly Japanese—R&D investment in the service sector was also significant. These industries accounted for 5 percent ($900 million) of the 1995 foreign R&D investment total, with most research being funded in computer, data processing, and research and management services. (See text table 4-12.)

[65] Totals are for R&D expenditures for U.S. affiliates of firms in which there is 10 percent or more foreign ownership. (See previous footnote.)

Summary

There was a resurgence in R&D investment in the United States in the mid-1990s. A prosperous economy has invigorated companies in both the manufacturing and service sectors, enabling them to allocate more resources toward the discovery of new knowledge and the application of that knowledge in the development of new products, processes, and services. An upsurge in innovation is further contributing to a buoyant economy.

At the same time that the private sector's role in maintaining the health of U.S. R&D enterprise has been expanding, the Federal Government's contribution has been receding, as the federal share has become less prominent in both the funding and the performance of R&D. As a result of these two divergent funding trends, the composition of the nation's R&D investment is slowly shifting. For example, recently, a growing percentage of the nation's R&D total has been directed toward nondefense activities. While industry has focused its R&D on new product development, the Federal Government historically has been the primary funding source for basic research activities.

Text table 4-12.
R&D performed in the United States by affiliates of foreign companies, by selected region/country and industry of affiliate: 1995
(Millions of dollars)

		Manufacturing								
Region/country	All industries	Total	Drugs & medicines	Other chemicals	Machinery	Electrical equipment	Transportation equipment	Instruments	Service industries[a]	Other industries[b]
Total	17,666	14,743	5,255	3,071	1,089	2,770	478	682	922	2,001
Canada	1,396	1,320	*	24	13	D	D	D	18	58
Europe	13,370	11,926	5,167	2,962	584	1,482	316	506	557	887
France	1,844	1,594	——579——		127	424	52	106	35	215
Germany	3,976	3,676	759	2,026	——583——		144	45	38	262
Netherlands	838	609	1	303	*	D	7	D	35	194
Switzerland	3,088	2,688	2,268	47	89	110	*	D	351	49
United Kingdom	2,419	2,178	——1,420——		94	103	83	206	80	161
Asia and Pacific	2,435	1,228	77	78	467	D	D	48	339	868
Japan	1,867	1,052	70	60	389	192	39	38	323	492
Western Hemisphere	280	148	0	*	3	3	1	D	3	129
Middle East	98	D	11	0	10	D	0	6	5	D
Africa	68	D	0	0	2	0	0	0	*	D

* = less than $500,000; D = withheld to avoid disclosing operations of individual companies

NOTES: Not all countries and industries are shown. Includes foreign direct investments of nonbank U.S. affiliates only. Includes R&D expenditures conducted by and for the foreign affiliates. Excludes expenditures for R&D conducted for others under a contract. Expenditures differ from Bureau of Economic Analysis-reported expenditures in appendix table 4-53.

[a]Includes computer and data processing services ($402 million) and accounting, research, and management services ($456 million).

[b]Includes wholesale trade ($1,412 million) and petroleum ($387 million).

SOURCE: U.S. Bureau of Economic Analysis, *Foreign Direct Investment in the United States: Operations of U.S. Affiliates of Foreign Companies Preliminary 1995 Estimates* (Washington, DC: U.S. Government Printing Office, 1997).

Science & Engineering Indicators - 1998

Although more positive than negative indicators of the health of R&D funding have appeared in recent years, there is some cause for concern that short-term R&D may be displacing the longer term quest for new knowledge and breakthrough discoveries. To compensate for what may be a recession in long-term fundamental research, new trends have been emerging. Greater reliance is being placed on the academic research community, and all sectors have expanded their participation in a variety of domestic and international partnerships both within and across sectors. The rapid rise in global R&D investments is evident from the expansion of industry's overseas R&D spending and the even more rapid rise in foreign firms' R&D spending in the United States. These domestic and foreign collaborations permit performers to pool and leverage resources, reduce costs, and share the risks associated with research activities. In addition, such alliances and international investments open a host of new scientific opportunities for R&D performers, enabling them to accelerate the exploration and deployment of promising new research and technologies that undoubtedly will be the source of tomorrow's new products and services.

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